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AGE PROBLEM OF CRYSTALLINE SCHISTS
IN THE MASSIF CENTRAL OF FRANCE[1,2]

by

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he well-defined region of uplifts in the pre-
relief of Central France constitute an area
gneiss, crystalline schist, and granites, gen-
ly known as the Massif Central. The mas-
s fringed by the Parisian basin (syneclise)
he north, and on the south and southwest by
Aquitanian basin (syneclise), while in the
it is delimited by the meridional Rhone de-
ssion which separates the "crystalline block"
he Massif Central from the folded zone of the
s and Jura mountains (Figure 1).

he fossiliferous zone of Paleozoic deposits
eveloped almost exclusively along the peri-
ry of the Massif Central: in the Montagne
re, the region of the Cevennes, Morvan,
nnais, and in the southern reaches of the
ousin. Carboniferous upper coal measures
preserved in individual narrow troughs of the
sif. Considerable areas in the northeastern
t of the plateau are occupied by Tertiary and
ternary deposits in the Limagne and Forez
ressions. Tertiary and Quaternary extrusive
ks (the volcanic "chains" of Puy, Sioule, the
ssifs" of Mont Doré, Cezaler, Cantal,
rac; the vulcanoes: Velay, Coiron, and Vi-
ais) are abundantly represented.

or a long time a view was entertained in geo-
c literature (E. Suess, 1885; M. Bertran,
7) that the Massif Central is a part of the
rcynian folded zone, within the bounds of
ch the Armorican northwesterly trends change
uptly to the Variscian northeasterly strike.
e Hercynian structure of the massif is fre-
ntly represented in the form of the Roman V

opening towards the north. However, after the
investigations carried out by G. Mouret [26],
F. Delafond [14], E. Raguin [30], and the
fundamental review by S. Bubnov [2] of extral-
pine European geology, serious doubts have
arisen regarding the uniformity of the massif's
inner structure and the contemporaneity of its
folding. A theory was advanced to the effect that
more ancient "cores" (F. Delafond's "Limoges
block", etc.) are involved in the massif's struc-
ture. Subsequently these ideas have acquired a
new and graphic expression in the works of J.
Jung, M. Roques, P. Lapadu-Hargues, M.
Chenevoy, F. Forestier, and J. Peterlongo.

The uppermost age limit of the series of
crystalline schists and granites in the Massif
Central has been long since unequivocally as-
signed to the Pre-Pennsylvanian (Pre-Stephanian).
Stephanian carboniferous lacustrine deposits are
developed in numerous shallow hollows in the
massif. They lie everywhere with sharp uncon-
formity upon the various section elements of the
crystalline schist series, as well as on granite.
The Upper Carboniferous is not metamorphosed
anywhere. At the same time, the Stephanian de-
posits are usually contorted as a result of Saal-
ian folding.

Half a century ago, J. Bergeron [11] identified
in the Montagne Noire, i. e., at the southern ex-
tremity of the Massif Central, a thick series of
Paleozoic sedimentary rocks with a faunal as-
semblage corresponding to the greater part of
the Paleozoic sequence ranging from the Lower
Cambrian and including the Visean. Approxi-
mately at the same time, A. Michel-Levy [24]
revealed a Paleozoic faunizone (Upper Devonian
and Visean) at the extreme northern part of the
Massif Central in the region of the Morvan.
These important observations served as a basis
for classifying the Massif Central of France as
a Hercynian folded structures. It was believed
that the sedimentary Paleozoic (Pre-Pennsylvan-
ian, Pre-Stephanian) rocks north of the Black
Mountains and south of the Morvan "change" into
the series of crystalline schists as one moves
deeper into the Massif Central. In proceeding
from these positions it was natural to estimate
the age of the series on the basis of the time
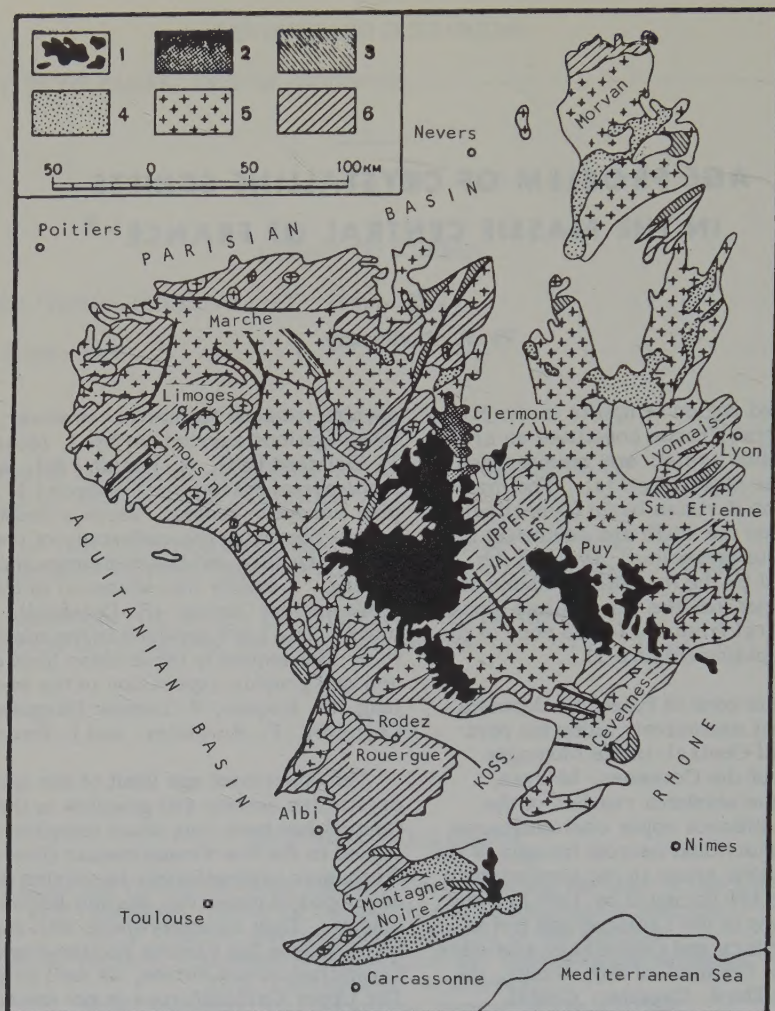
FIGURE 1. Schematic geologic map of the French Massif Central. Borrowed
from the "Itinerary" of the excursion of the
Massif Central of 1958 [13].

1 - Neogene extrusive rocks; 2 - Quaternary extrusives; 3 - deposits of
the Carboniferous Stephanian stage; 4 - Paleozoic Pre-Stephanian deposits;
5 - plutonic rocks; 6 - crystalline schist.

interval from the Cambrian inclusive to the
Visean. The date of metamorphism was believed
to be Hercynian, and the age of the folding Sude-
tic, Hercynides (Post-Visean, but Pre-Stephanian
folding). It is obvious that in the light of this
theory there exists no evidence whatever of the
Caledonian, or even the more ancient, Pre-
cambrian orogeny in the Massif Central.

This superficially logical and convincing
theory has many followers. One of them is A.
Demay [15] who bases his beliefs on the struc-
tural, stratigraphic, and magmatic relation-
ships between the Massif Central and Brittany.
In his opinion the Paleozoic, perhaps partly

Precambrian, crystalline schists extend from
southern Armorica into northern and southern
Limousin, and further on into the central and
eastern parts of the Massif Central. The latte
was the arena of grandiose manifestations of
Paleozoic metamorphism, of indubitably Hercy
ian orogenesis, Hercynian (Carboniferous) bi-
nary granites ("granulites"), and "almost cer-
tainly" of Carboniferous injected gneisses and
orthogneisses.

A situation has been created in the French
geologic literature very similar to that which
prevailed in Russia some 25-30 years ago dur
the discussion of the "ancient sinciput of Asia"

course of this discussion M. M. Tetyayev
asserted that there exists a continuous
transition" from the non-metamorphosed lower
zoic included in the southeastern fringes of
Siberian platform into the metamorphic se-
ries the Balkalian highlands. At the present
it is known [1, 3, 4, 5, 10] that the lower
zoic (Cambrian) deposits play a relatively
minor role in the structure of the metamorphic
series of the upland. The Caledonian stage of
development was very localized and the
overwhelming portion of the metamorphic series
back to the Precambrian.

The interesting investigations by J. Jung and
Roques have opened the way for a new ap-
proach to the solution of the problems dealing
the stratigraphy, tectonics, and meta-
morphism of the crystalline schist series of the
Massif Central of France.

According to J. Jung and M. Roques [18], the
al composition of the rocks altered into
crystalline schists of the Massif Central was
uniform. For example, the Lower Limou-
series, which is, apparently, characteris-
of the other parts of the plateau, appears in
form of thick pelitic accumulations free from
internal breaks and unconformities. The pelitic
es is conformable with the volcanics, in the
position of which various sandstones are
prominant.

In spite of the fact that the Massif Central
well as the entire territory of France) has
thoroughly investigated, no supporting
marker beds have been revealed in either of the
ies. Under these circumstances, a detailed
stratigraphic subdivision of the crystalline
schists meets with exceptional difficulty.

J. Jung and M. Roques have originated and
developed [18] a doctrine on the zonal structure
the "normal" crystalline schist formations.
These formations originating by topochemical

recrystallization of the initial rocks without any
noticeable alteration of their primary composi-
tion are termed "normal". The topochemical
metamorphism affected both series of sedi-
mentary and volcanic rocks, resulting in the
emergence of a number of thick zones located in
a definite vertical succession (zones of isometa-
morphism). For the Massif Central these zones
are as follows (see Table 1).

The vertical sequence of topochemical zones
is in places different than that shown in the
Table. Thus, in the Marche district northwest
of the Massif Central, an inversion of the iso-
metamorphic zones occurs: the dimicaceous
schists form the core of the anticline with the
gneiss and migmatite embedded in its limbs.
Such phenomena are attributable to tectonic
causes, namely, to the development of over-
thrust folding.

Granite and migmatite serve as the sub-
stratum for the lower gneiss. The migmatite,
however, does not occupy a strictly fixed posi-
tion in the sequence of isometamorphic zones.
J. Jung and M. Roques believe [18] that the level
of the "migmatization front" is at its highest in
the southern part of the Massif Central (Montagne
Noire, Cevennes) where it passes into the zone
of the upper mica schist. Farther north, this
level manifests a gradual dip and coincides with
the zone of the ultra-low gneiss at the extreme
northern edge of the plateau (Morvan).

The isometamorphic zone method is fairly
widely applied in France for geologic mapping at
different scales. The zones of isometamorphism
have been, so to say, substituted for the strati-
graphic elements of the crystalline schists se-
ries. The existing geologic maps of the Massif
Central should really not be referred to as geo-
logic, but rather as petrographic maps, or maps
of isometamorphic zones with granitization and
migmatization phenomena superimposed upon
them.

Table 1

Stratigraphic Position of the Zones of Isometamorphism

Supporting facies	Description of zone	Thickness, m
Clay slate	Non-metamorphic	4000
Chloritic and sericitic schist	Zone of the upper mica schist	3000
Dimicaceous schist	Zone of the lower mica schist	3000
Dimicaceous gneisse	" upper gneiss	4000
Biotite gneiss	" lower gneiss	6000
Cordierite gneiss	" ultra-low gneiss	—
Total		20 000

The zoning method of J. Jung and M. Roques, interesting and prolific as it is, at the same time conceals certain dangerous features. In my opinion, the main objection is indicated by the fact that a direct and constant coincidence of the isometamorphic zones with definite stratigraphic levels is not altogether mandatory. Meanwhile, it is precisely on the assumption of the constancy of this relationship that the practice of geologic mapping is, in fact, based in the Massif Central. This assumption also serves as the basis for certain theoretical postulates, which, as a matter of fact, are very interesting. I have in mind J. Jung's work on the zoning and the age of the crystalline schist formations in the Hercynian massifs of France [19]. In this paper all the zones of isometamorphism referred to above are arranged not only in strict relative vertical order, but also correspond to a definite stage of historical development of the Massif Central.

With respect to the entire area covered by the massif, it is difficult to accept, a priori, that there exists a constancy in the thickness and facies of the individual elements in the series of crystalline schists formed in consequence of metamorphism of geosynclinal deposits which are in part flysch accumulations [12, 13, 19] It was observed long ago by M. Roques [31] the thickness of the isometamorphic zones va within fairly broad limits from one region of Massif Central to another. The same phenom has attracted the attention of P. Lapadu-Harg [20], F. Forestier [17], and M. Chenevoy [It appeared that the boundaries of the zones of isometamorphism are not infrequently spatial oriented in a manner other than parallel to the primary foliation plane. A "lensing" of indivi metamorphic zones occurs.

Under these conditions, a correlation betw the existing zone maps and purely geologic ma based on stratigraphy will not be easy. After such a correlation, it will become possible fo the first time to obtain an objective idea of the tectonics of the series of crystalline schists in the Massif Central.

J. Jung [19] substantiates the formation of ancient Precambrian "cores" in the Massif

FIGURE 2. Occurrence of various types of crystalline schist series in France, after J. Jung [19]

Vertical hachures: series of the Pyrenean, Armorican, and Limousinian types; horizontal hachures: series of the Auvergne and Vosges type.

tral and the Vosges (Figure 2) by elucidating
relationships between the crystalline base-
nt rock and the overlying series of Paleozoic
limentary formations. It appeared that there
e two types of such relationships. The first,
Pyrenean type, is characterized by the Paleo-
c sedimentary series (Cambrian-Dinantian),
ich overlies conformably the zone of the top
per Precambrian mica schists (Brioverian,
ra-Cambrian, as called by French geologists
2, 29]). According to J. Jung, the Pyrenean
e of section is characteristics of the western
imousin) and southern (Rouerge and Cevennes)
rts of the Massif Central. The first type of
rrelation between the ancient series of crys-
lline schists and the overlying sedimentary
leozoic series is in full accord with J. Berg-
on's and A. Michel-Levy's concept of a
ingle Hercynian series". The second (Au-
rgne) type is identified in the central and
rthern parts of the Massif Central (Auvergne,
yonnais, Morvan). A sharp discordance is to
e observed here between the Paleozoic mantle
d the series of metamorphic rocks including
l the zones of isometamorphism.

In this case, therefore, there is no basis for
a single Hercynian series". The crystalline
chists of the Auvergne, Lyonnais, and Morvan
nquestionably represent the ancient Pre-
ercynian formations. These sedimentary,
yroclastic, and volcanic rocks were metamor-
hosed at the end of the Precambrian. The
block" of Auvergne, Morvan, and the Vosges,
ccording to J. Jung, was formed in the process
f Cadomian (Assintian, Baykalian, late Pre-
ambrian) folding, whereas the structural gar-
ands which fringe it along the periphery con-
stitute the more recent Hercynian formations.

The surveys of recent years carried out after
he publication of J. Jung's interesting study
19] have brought to light many new features.

M. Chenevoy [12] was able to show that a
series of crystalline schists occur in the west-
ern and northwestern part of the Massif Central
Marche, northern Limousin). It is similar to
he Auvergne formation and may be easily dif-
erentiated by the zone method as a complete
succession of zones of isometamorphism. The
Limousin series emerged in the process of
metamorphism involving the thich flysch ac-
cumulations. Apart from the primary sedi-
mentary rocks, which are practically free of the
carbonate facies, the composition of the series
ncludes lavas and tuffs (spilitic keratophyre for-
nation), as well as basic (gabbro) and ultrabasic
peridotite, eclogite) intrusions.

Of exceptional interest is the fact that the
northern Limousin series of crystalline schists
urned out to be polymetamorphic. Two stages
f metamorphism and migmatization are clearly
iscernible, a fact which has become evident to
he participants of the third Session of the

International Association for the Study of the
Deep Zones in the Earth's Crust. The first stage
of metamorphism came as a result of topochemi-
cal recrystallization of the initial rocks. It was
then that the zones of isometamorphism identified
by J. Jung and M. Roques were formed. This is
the "single metamorphic series extending from
the zone of the lower gneiss to that of the upper
mica schist. No unconformity was registered in
this series, and this fact reflects its strati-
graphic unity beyond all doubt" [12].

Embedded at the base of the northern Limousin
upper gneiss zone are the ancient "migmatites of
the basement" [12] represented by the so-called
Aubusson gneiss. These rocks are particularly
widespread in the easterly parts of the Massif
Central, in the Auvergne. The Aubusson gneiss
is made up of anatexites with sillimanite and
cordierite and assume only gradually an individ-
ualized character among the sillimanitic gneisses.
Here, it is impossible to delineate a clear-cut
"front of magmitization".

An intensive folding occurred after the initial
stage of topochemical metamorphism and the for-
mation of the basement migmatites. Then came
the second stage of metamorphism and potassium
replacement. The second stage metamorphism
is evidenced with unequal degree of intensity in
different parts of northern Limousin. Its con-
crete manifestation is the paragenesis of biotite,
muscovite, and tourmaline occurring in various
zones of ancient isometamorphism of the first
stage, in particular, in the ancient zone of the
upper mica schist. The second generation mica
laminae are not uncommonly positioned at a
slant to the primary schistosity of the rocks.

Another manifestation of the second stage
metamorphism is potassium metasomatism re-
sponsible for the formation of the so-called
"stratoidal migmatites" which consist of different
sizes of lenses at different stratigraphic levels
of the metamorphic series. The "stratoidal
migmatites" possess textural and structural fea-
tures and a chemical affinity sharply differing
from the corresponding characteristics inherent
in the ancient "basement migmatites". Peculiar
to the "stratoidal migmatites" is an embrechite
texture (as a result of laminar migmatization).
The mineral formations in them (quartz and
feldspars) are always regularly oriented in con-
cordance with the enclosing rocks.

Related to the second, superimposed, stage
of metamorphism was the formation of the meta-
somatic "oriented" diorites emerging as a result
of basic replacement. Similar to the "stratoidal
migmatites", these diorites occur as different-
size lenses in different parts of the section of the
crystalline schist series.

The second period of deformation must have
taken place after the second stage metamorphism,
or, possibly, partly simultaneously with it.

These deformations were energetic, though differing in character from the preceding more ancient dislocations. In the course of the earliest phase of tectogenesis, there appeared in northern Limousin a system of linear, strongly plicated folds with a predominantly northwesterly Armorican trend. The later, second, period of deformation is associated with the formation of tectonic "arcs" shaped into major folds with a large radius of curvature, and also with the development of faults striking in a westerly and northwesterly direction, as well as with the more recent meridionally oriented fractures. The large Argentat fault belongs to the later category (Figures 1 and 3).
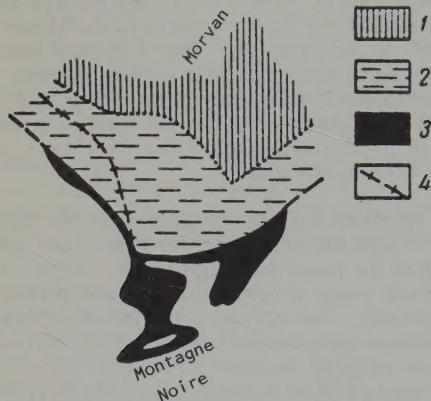

FIGURE 3. Schematic structure of the Massif Central.

1 - northern zone; immediately overlying the ancient crystalline basement structure is the Devonian-Dinantian geosynclinal series; the Cadomian fold is deformed by Hercynian folding and faults; three-stage metamorphism of the crystalline basement. 2 - geosynclinal zone formed after termination of the Cadomian, Precambrian folding; positive structure as of the beginning of the Paleozoic era; two-stage Pre-Hercynian metamorphism. 3 - southern zone; continuous geosynclinal sedimentation from the Brioverian to the Ordovician, including the Visean at the extreme south; arena of the Caledonian and Hercynian folding; the first stage of regional Brioverian metamorphism is not traceable. 4 - ancient (Brioverian) deep-seated fault of Argentat.

M. Chenevoy assigns the ancient metamorphism and the first phase of tectogenesis to the Caledonian cycle. The second tectogenetic phase, as well as the recurrent metamorphism, he associates with the Hercynides. As we shall see from further discussion, the age of all these processes is older, dating to the Pre-Hercynian.

The new investigations carried out by F. Forestier [13, 16, 17] involved a part of the mid-section of the Massif Central and its southeastern extremity (the area of the upper reaches

of the Allier and the headwater region of the Loire). According to J. Jung [19] the southeastern part of the ancient Precambrian "core" of the Massif Central is situated here together with the adjacent zone of the peripheral Paleozoic folded fringe.

An ancient series of crystalline schists made up of the very same zones of early topochemical metamorphism occurs in the region surveyed by F. Forestier, as well as in northern Limousin. Only the zone of upper mica schist is absent here. It is curious that F. Forestier, too, has uncovered clear evidence of second-stage metamorphism ("stratoidal migmatites"), as the participants of the third Session of the International Association for the Study of the Deep zones in the Earth's Crust may have had the opportunity to see.

A bed of rocks enriched by hyanite is distinctly observable in some places in the zone of the lower mica schist. This fact justifies the hope that it may be possible to identify the local horizon markers in the section of the crystalline schist series, which is of great importance for the study of its stratigraphy.

The series of crystalline schists is contorted into strongly compressed folds, similar to those of the Limousin, which virgate in the northwesterly (the Massiac syncline) and the northeasterly (Déège-Cenouïr and Allairat) directions. The "stratoidal" migmatites (second-stage migmatization) form a major meridional "arc" Chaise Dieu - Lagogne, a latitudinal "arc" Piols, and a small anticline Anse. By analogy with the Limousin, it might be assumed that these "arcs" probably represent the most recent superpositions of the second-stage deformation.

It appears to me that no objective indications were obtained in the area surveyed by F. Forestier relative to the existence of any kind of boundary between the ancient Precambrian "cores" of the Massif Central and the peripheral Paleozoic folding intimated by J. Jung [19].

The age of the series of crystalline schist, as well as that of the folding and metamorphism of both stages, is indubitably Pre-Pennsylvanian, Pre-Stephanian, in the opinion of F. Forestier.

Of particular importance for the age determination of the two-stage folding and metamorphism series in the Massif Central of France are the new data produced by J. Peterlongo [13, 27]. His surveys covered that part of the massif's eastern fringe which includes the Lyonnais, Tarare, and Beaujolais mountains. The southern part of the region (Lyonnais) is made up of the ancient series of crystalline schists, whose base is formed by the "basement migmatites", with the zones of lower and upper gneiss lying on the top. Also observable are younger

ormations similar to the "stratoidal" migmat-
es. In other words, the Lyonnais series is
otally comparable to the similar Limousin
series of the Allier and Loire headwater regions.
This is the initial and highly significant result of
Peterlongo's investigations. It emphasizes the
act of the existence at the eastern extremity of
he Massif Central of an ancient series of crys-
alline schists which has experienced as in other
arts of the Massif Central, a two-stage meta-
morphism, two-stage migmatization, and a two-
hase folding, the "phases" of which are sepa-
ated from one another by a long period of time.

The second, and also highly important result
of J. Petrolongo's survey consists in the follow-
ng. He was able to prove the existence of a
second, younger series of volcanic and sedi-
mentary formations which he called the Bre-
vennean series in the northeastern portion of
he Massif Central. This is a characteristic
spilitic keratophyre formation including in its
composition "the basic components transformed
into chlorite-epidote rocks, or into amphibolites,
depending on the degree of metamorphism which
subsides as one moves from the south to the
north. Also present here are albitophyres and
very acidic rocks (rhyolites and rhyolitic ashes),
transformed into felsitic leptynites" ([13], p.
29). Sedimentary rocks play a subordinate role
in the composition of the Brevenne series. These
are graywacke, a variety of slate and limestone
interstratified with volcanic and pyroclastic for-
mations.

Associated with the Brevenne series are vari-
ous intrusive rocks which differ in form (blanket
deposits, laccolithic sills), and in composition
(serpentinite, norite, gabbro, diorites, and the
relatively more recent alkalic granite). A high
content of sodium and exceptional poverty in
potassium is characteristic of all these mag-
matic rocks.

Lower Visean fossils were found in the lime-
stone and schist of the upper part of the Brevenne
series. Famennian albitophyres of the Morvan
region (in the northwestern part of the Massif
Central) studied by A. Michel-Levy [24] are
similar to the lavas of the Brevenne series.
Thus, the age of this series may be clearly
Upper Devonian - Lower Carboniferous.

The relationship of the Brevenne series to the
ancient crystalline schist was established by J.
Peterlongo quite clearly. The sedimentary -
volcanic Brevennes series is bedded transgres-
sively and unconformably over the gneiss and
migmatite. This fact permits the Pre-Devonian
age to be considered proven for the crystalline
schist series which in Pre-Devonian time was
subjected to a two-stage folding and a two-
stage process of metamorphism and migmati-
zation.

The identity of composition, metamorphic

history, and development of tectonic structures
established by the new observations of French
geologists for the ancient series of the Limousin,
the headwater regions of the Loire and Allier, as
well as for the Lyonnais, is of exceptional im-
portance. The existence of the ancient "core" in
the Massif Central which was referred to by F.
Delafond, S. Bubnov, E. Raguin, and J. Jung is
thereby substantiated, as we see, by new and
conclusive proof. It transpires also that the
size of the "core" is larger than envisoned by
J. Jung. Within its borders one should include
the greater part of the "Paleozoic peripheral
zone": Limousin, Lyonnais, and the upper
reaches of the Loire. In the light of the new
observations, the hypothesis relative to the
"single Hercynian series" appears to be totally
baseless for the largest part of the Massif
Central of France.

What is the precise age of the crystalline
schist series of the "Auvergne type" [19]? As
already stated, J. Jung believes this series to
be Precambrian. M. Roques [13], while em-
phasizing the unquestionably Pre-Devonian age
of the series, observes that the upper part of it
resembles the Cambrian-Silurian formations of
the Vendée, and that "the Caledonian age of the
Auvergne series is quite possible".

M. Chenevoy is inclined to share this opinion
[12] in attempting to substantiate it through
lithologic and stratigraphic comparison and on
the basis of absolute geochronology. He cor-
relates the upper part of the Limousinian series,
the, so-called Gartan series, with the upper part
of the section of the south Limousin metamorphic
series in which encrinites were disclosed by M.
Roques [31]. In referring to M. Toral's opinion,
J. Jung considers this faunal assemblage as being
probably of Devonian age. M. Roques assigns it
to the Cambrian, while A. Demay regards it as
Silurian. If this is readlly Silurian, or as it
seems to be more probable, a Devonian fauna,
then the correlation of the Gartan series of
northern Linousin with the Cambrian-Silurian
system of the Vandée as is done by M. Chenevoy
is baseless. Moreover, the Cambrian and Ordo-
vician sequence of the Vandée bears no resem-
blance to M. Chenevoy's Limousin section. Un-
like the Limousin series, the Cambrian of the
Vandée lies transgressively and discordantly
[28] upon the Brioverian rocks (belonging to the
Upper Precambrian). The Cambrian section of
the Vandée begins with the Sigournet conglom-
erate above which lie the redbeds. No such
rocks are to be observed in the Gartan series.

M. Chenevoy estimates the absolute age of
the ectinites (410 to 480 million years), of the
migmatites of the basement (385 to 400 million
years), of the "stratoidal" migmatites (255 to
298 million years) and of a few granites. At the
first glance these figures appear to be fairly
convincing. However, a closer scrutiny exposes
their unreliability. The porphyritic Souterraine

granite (330 million years) turned out to be older than the Gueret granites (270 million years). This, M. Chenevoy himself acknowledges, contradicts field observations and the petrographic data. The Devonian age of the Brame granite, which is equal to that of the "stratoidal" migmatites, is considerably underrated as M. Chenevoy himself again admits. According to him the "stratoidal" migmatites correspond to the Middle and Upper Devonian. This is in sharp contradiction with the geologic data of J. Peterlongo referred to earlier in this discussion.

It appears to me that in determining the absolute age of the various rocks in the Massif Central, M. Chenevoy has failed to give due consideration to the following facts. That the massif contains polycyclic formations [25], that the geologic history of this region is highly complex, and that the ancient schists and granites were subjected both to physical and chemical treatment not only in the Cadomian, but also in the Caledonian and Hercynian orogenies. Is it possible under these circumstances to rely firmly on the steadiness of the isotopic composition of lead? There exists a sufficiently well-grounded opinion among geochemists that "as a result of heating of minerals and rocks, the different forms of lead sublimate at varying rates, in consequence whereof a shifting of the isotopic composition of lead is observable. In natural conditions various native formations may sustain losses or may be enriched by lead isotopes under the influence of relatively low temperatures" ([8], p. 29).

The figures obtained by M. Chenevoy do not reflect so much the absolute age of one or another type of rock in the Massif Central. Rather, they express the intensity of the treatment to which the mineral components of the ancient rocks were subjected as a result of the more recent tectonic and physiochemical processes. The higher the energy of the subsequently superimposed processes, the less reliable are the efforts to determine the absolute age of ancient series. We shall restrict ourselves here to only one graphic and conclusive example. The figures pertaining to the absolute age of the rocks in the ancient "Algonkian" crystalline basement of the Schwartzwald, very heavily deformed in the Hercynian orogeny [23], are practically indistinguishable from the respective values peculiar to the rocks of the unquestionably Hercynian complex [21].

In the light of all the arguments in this discussion, I am inclined to believe that the opinion expressed by J. Jung and his predecessors concerning the Precambrian age of the rocks composing the "core" of the Massif Central fully retains its significance. The investigations carried out by M. Chenevoy, F. Forestier, J. Peterlongo, and other investigators justify the belief that the size of this "core" was larger

than estimated by J. Jung [19], and that the greater part of the Limousin area, the territory of the Marche and Lyonnais, together with the Auvergne and Morvan, should also be included therein. Characteristic of the entire "core" region is the energetic folding dating to the end of the Precambrian era (Cadomian, Assintian, Early Baykalian, late Proterozoic folding), the development of progressive topochemical metamorphism, migmatization of the basal complex, and the emergence of anatexites (Figure 3). The second-stage metamorphism ("stratoidal" migmatites), and the formation of folds with a large radius of curvature, apparently evidence the reaction of the "core" to the movement of the Caledonian cycle in the neighboring geosynclinal regions. To the Hercynian movement, the "core" reacted by developing a large number of deep faults along which occurred the formation of the late orogenic and post-orogenic granitic bodies. Contact aureoles formed in the zone of abutment of these intrusions against the Precambrian crystalline schists. As it was shown by J. Peterlongo's surveys [12, 27], the ancient basement rocks in the Lyonnais region were subjecged to retrograde metamorphism (the third local stage of metamorphism) during the development of Hercynian structures.

The Argentat fault zone was, apparently, formed as far back as the development of the ancient Brioverian geosyncline and served as a boundary between the Limousin flysch and the "pelitic" Brioverian formations of the more westerly sections of the Massif Central as indicated by M. Chenevoy [12, 13]. Judging by F. Forrestier's observations, the transition of the northwesterly Armorican into the northeasterly Variscian trend takes place in the middle part of the Massif Central as was assumed by E. Suess and M. Bertran. The transition from one type of trends to another, apparently, occurs rapidly but smoothly, in a manner similar to that observable near the southern extremity of Lake Baykal, where the axes of the Sayan northwesterly Precambrian folds change their direction for the northwestern Baykalian trend [1, 3, 4, 5, 10].

Judging by all indications, the merging of the Armorican and Variscian trends in the region of the Massif Central in the form of an arc with its bulge facing south must have occurred a very long time ago in the process of Cadomian (Assintian, Early Baykalian, late Proterozoic) folding.

It seems to me that this essential fact should be borne in mind when analyzing the Caledonian and Hercynian structures of western Europe.

To these phenomena and conclusions we shall revert in the next study confined to the analysis of the structure and development of the "Hercynian Massifs" of France and southern Germany.

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SOME GENERAL TECTONIC PROBLEMS OF THE ARCTIC ZONE[1,2]

by

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PRELIMINARY REMARKS

For purposes of tectonic analysis the Arctic region is of considerable interest. Folds of highly diversified origin are to be found here, ranging in age from the most ancient to the most recent orogenies. This fact facilitates their comparison and correlation. Moreover, the problem of intercontinental structural relationships is conspicuous in this area and, consequently, the problem of origin of the Arctic oceanic deeps. Many theories have been published reflecting a variety of opinions concerning the general tectonic structure of the Arctic zone. All of them, however, are exceedingly shallow and usually require no more than a single magazine page in print.

In 1959, a 1:7,000,000 polychrome tectonic map of the Arctic plotted on a normal cartographic projection was constructed at the Geological Institute of the Soviet Academy of Sciences. The scale adopted made it possible to depict the peculiarities of the crustal structure in the Arctic zone in great detail.

Construction of general tectonic maps for the major parts of the globe has, in fact, developed at the present time into the independent scientific discipline of tectonics. This development took place relatively recently, in post-war years, and was initiated for a number of reasons. The principal reasons, it appears to us, were: 1) abundant accumulation of factual information on concrete tectonic structures called for a generalization; 2) a need has arisen for new means to expand theoretical research dealing with the structure and development of the earth, and finally, 3) it has become necessary to widen the scope of inquiry into the general regularities governing the distribution of mineral concentrations in the earth's crust.

Particularly valuable experience in preparation of such maps was gained in the Soviet Union.

Reference is made here to the general tectonic maps of the U. S. S. R. published in 1953 and 1956. The tectonic map of the U. S. S. R. has, in fact, served as the basic starting point in the creation of a tectonic map of the Arctic, particularly so, since more than one half of the global Arctic expanse is confined within the boundaries of the Soviet Union.

Geologic information on the Arctic is available to a varying degree. On the whole, one could say that the Soviet sector is by now explored in detail. Among numerous study groups in this country, a considerable contribution in this respect was made by the investigators of the Institute of Arctic Geology where a general geologic map of the northern territories of the U. S. S. R. [7] was prepared and extensive factual material was thereby generalized.

Detailed and important geologic studies of the corresponding Arctic regions were completed by Finnish, Swedish [68] and Norwegian geologists [41, 66]. There also appeared recently a number of interesting works and maps dealing with the tectonics of Greenland [55, 56, 62, 63, 75, 77 and others], Canada [60, 81] and Alaska [47, 76, etc.].

Data on the bottom relief of the Arctic Ocean is of great importance for a correct understanding of the earth's crustal structure. Among the greatest achievements in this field is the discovery by Soviet explorers of the huge underwater Lomonosov Ridge which extends from the Novosibirskiye Islands across the North Pole area to the islands of the Canadian Arctic Archipelago. The newest bathymetric map of the Arctic was recently published by A. F. Treshnikov [40].

Many guesses and hypotheses were made by prominent geologists in different countries on the structure of the crust in the Arctic. For instance, E. Suess surmised that the folded structures of the Verkhoyansk highlands dip into the waters of the Arctic Ocean and extend underwater to the shores of Grant's Land located in the northern part of the Canadian Arctic archipelago. E. Og holds an opposite view in believing

FIGURE 1. Schematic Tectonic Map of the Arctic Zone.

Regions of Pre-Riphean Folding of the Ancient Platforms: 1 - Exposures of the folded basement of the ancient platforms. Platform mantle: 2 - up to 2000 m thick; 3 - more than 2000 m thick; 4 - without subdivision according to thickness (primarily Riphean and Lower Paleozoic); 5 - middle and upper Paleozoic, Triassic in places; 6 - Mesozoic (partially of the epi-Caledonian platform in Greenland); 7 - assumed boundaries of the ancient platforms in submerged areas.

Regions of Baykalian Folding: 8 - Precambrian folded complexes; 9 - platform covering of the Pre-Riphean platforms.

Regions of Caledonian Folding: 10 - outcrop of the Pre-Riphean folded basement and the lower structural stage (Riphean, Cambrian in places); 11 - middle structural stage (O-S); 12 - upper structural stage, internal troughs (D-C); 13 - attenuation zone of the Caledonids; 14 - assumed boundaries of the caledonids in underwater areas.

Regions of the Hercynian Folding: 15 - exposures of the Pre-Riphean folded base; 16 - lower and middle structural stages (Riphean-Paleozoic). Upper structural stage; 17 - internal troughs (C_3-T_1); 18 - foredeeps (C_3-T_1). Attenuation zones of the hercynids and formations similar to them; 19 - lower and middle structural stages (Riphean-Paleozoic); 20 - upper structural stages $(P-T_1)$. Platform mantle on the epi-Paleozoic platforms; 21 - up to 3000 m thick; 22 - more than 3000 m thick; 23 - mantle undifferentiated according to thickness; 24 - assumed boundaries of the hercynids in underwater areas.

Regions of Mesozoic Folding: Basement outcrops: 25 - formed by Pre-Cambrian folded rocks, and also by Riphean rocks in Alaska and western Canada; 26 - same with a platform covering of the Paleozoic and in places also of Riphean; 27 - formed by folded, but not geosynclinal rocks of the lower and middle Paleozoic, as well as Riphean in places. Lower structural stage: 28 - lower substage (C_3-T_1); 29 - middle and upper substage (T_2-J_2). Upper structural stage: 30 - internal troughs $(J_3-Cr, Tr$ in spots); 31 - foredeeps (J_3-Cr); 32 - internal Cenozoic troughs.

Regions of Kamchatkan Folding: 33 - exposures of Precambrian and Paleozoic folded base and lower structural stage (Pz_2-Cr), 34 - middle structural stage (Cr_2-Pg); 35 - upper structural stage $(N-Q)$; 36 - volcanic complex in the peripheral belt of Cenozoic folding.

Other Symbols: 37 - Mesozoic and Cenozoic granitoids correlative with the regions of Mesozoic and Cenozoic folding; 38 - major superimposed subsidence zones (deep-sea depressions); 39 - contours of major tectonic structures; 40 - certain faults; 41 - volcanoes (active and dormant); 42 - salt domes.

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that the Arctic Ocean constitutes the most ancient, i.e., primeval, depression in the earth's crust. A Vegener [4] and his followers [80] believed that the trenches of the Polar basin formed as a result of disruption of a single continent and the subsequent drift of its parts southward from the pole. O. Holtedahl [66] compared the region of Arctic deeps with the Tarim block of central Asia.

More recently ideas have appeared suggesting that the structure of the earth's crust in the area covered by the Arctic Ocean was, until recently, similar to that which we observe at the present time on the continents and that subsequently the region subsided forming oceanic basins which, therefore, are of secondary origin.

This latter view was most graphically developed by N. S. Shatskiy in 1935 [43]. Later on, similar ideas were expressed by A. Eardley [19]. Most popular in the Soviet literature is the concept of N. S. Shatskiy.

Of the newest tectonic hypogheses pertaining to the Arctic we shall note here the interesting theories advanced by V. N. Saks, N. A. Belov, and N. N. Lapina [33] and by D. G. Panov [30]. They emphasize the secondary origin of the trenches in the Arctic Ocean. D. G. Panov briefly outlines the development of the ideas

relating to the general structure of the Arctic. Owing to limited space such an outline must be foregone in this article.

The tectonic map of the arctic was prepared under the editorship of N. S. Shatskiy. In reflecting the tectonics of the Soviet Arctic territory use was made in preparation of the tectonic maps of large sections constructed by the staff members of the Geological Institute of the Soviet Academy of Sciences. Consequently, the tectonic map of the Arctic must be considered as a product of the collective work done by the departments of regional and general tectonics of this Institute.

The basic tectonic classification in the map was made in accordance with the age of the folding. The ancient Pre-Riphean platforms, the baikalids, caledonids, hercynids, mesozoids, and the regions of Cenozoic folding, which are called Kamchatkan in the Pacific Ocean are represented by different colors. The relative depth at which the basement of the platforms is bedded and the structural stages in the folded regions are marked in shades of these colors. Special symbols are used to designate the foredeeps, intermontane areas, the boundaries of platforms and zones of folding of different age in submerged areas, and certain other tectonic elements. For the main part of dry land it turned out to be possible to represent tectonic

structures by different isolines, or in the form of axes of folds, main trends, and fractures.

Granitoid intrusions, the location of which strongly emphasizes the tectonic structure, are shown in the regions of Mesozoic and Cenozoic folding.

In providing the map with factual material a certain non-uniformity could not have been avoided. This is to be attributed mainly to the fact that certain Arctic regions are poorly explored geologically. Most hypothetical is the representation of the Polar-basin tectonics, and with respect to this section the map should be regarded as a sketch map.

In certain basic features, the map coincides with the tectonic chart of the Arctic put out by N. S. Shatskiy in 1935 [43]. It, therefore, essentially represents a further development of the ideas reflected in the chart. With regard to the tectonics of the continental part and the islands of the Soviet Arctic sector the map closely resembles the 1:5,000,000-scale map of the U.S.S.R. [37]. In dealing with the Taymyr Peninsula the new map reflects the ideas embodied in the first 1:4,000,000 tectonic map of the U.S.S.R. [36]. In a strongly schematized and somewhat revised form the map of the Arctic is shown in Figure 1.

1. THE ANCIENT PLATFORMS OF THE ARCTIC

From the schematic map it may be seen that huge areas in the Arctic (up to 60° N. Lat.) belong to the ancient (Pre-Riphean) platforms. Located here are the enormous Canadian shield [70, 84, 85], a considerable part of the Russian and the greatest part of the Siberian platforms. Apart from dry land, the ancient platforms, apparently, also occupy spacious expanses under the waters of the Polar basin.

One of these submarine platforms, the Hyperboreal abyssal plain, exists, we believe, in the eastern sector of the Arctic Ocean in the area occupied by the Beaufort basin. The existence of this platform north of Alaska is evidenced by a number of facts: 1) through exposure of the crystalline basement by boreholes at a depth of 720 m at Pt. Barrow, 2) by paleogeographic analysis revealing a washout area dating back to Permian time north of Alaska, and 3) by the presence south of Pt. Barrow in northern Alaska of a typical foredeep in the region of Mesozoic folding [47, 76].[3] The very concept "foredeep" indicates that the given tectonic structure was

formed at the junction of a platform and folded (geosynclinal) area [32]. In Asia, the Hyperboreal platform emerges on the islands of De Long Archipelago, where its lower Paleozoic mantle may be seen in places (e.g., Bennet Island) [22]. Moreover, an analysis of the trends of the tectonic structures at Novosibirskiye Islands and Vrangel' Island, and also in the littoral area of the continent, indirectly suggest that the edge of the platform must not be far away in this region. The western margins of the platform are determined by the position of a zone of sharply differentiated floor relief passing through the central part of the ocean and dividing it into two trenches.

A second platform structure is located, in our opinion, under the waters of the Barents sea, possibly reaching out to the westernmost islands of the Severnaya Zemlya archipelago. The ancient crystalline basement of the platform buried in places under the rocks of the sedimentary mantle is exposed on Northeast Land of Spitsbergen and on Belyy Island [30]. It appears that a similar structure is also peculiar to Victoria Island, the Franz Joseph Land archipelago, and Vize and Ushakov Islands, where the Mesozoic (and Paleozoic on Victoria Island) sedimentary mantle was revealed [13, 14, 15] even though the crystalline basement is buried.

It should be noted here that there is no concurrence of opinion with regard to the tectonic nature of Spitsbergen [57, 72, 74]. Views are still being expressed to the effect that Spitsbergen as a whole should be assigned to the zone of Caledonian folding. In supporting K. A. Klitin, who has carried out a detailed analysis of Spitsbergen tectonics, I believe this point of view to be correct and am inclined to agree with him that the Northeast Land of Spitsbergen represents a structure of ancient platform type. New and interesting data in this respect were published by W. Harland [64]. According to his observations, non-metamorphosed strata consisting of arenaceous schistose rocks in the lower part of the section, and carbonaceous format formations in the upper part, were deposited transgressively over the deeply metamorphosed rocks of the Northeast Land of Spitsbergen (Archean?). The over-all thickness of the strata is 3 to 5 km. These strata are compared with the Hecla-Hook complex (late Precambrian -Middle Ordovician) developed within the confines of the western part of Spitsbergen, in New Friesland. This complex consists of strongly metamorphosed rocks (particularly in the lower part) which include crystalline schists, gneisses, quartzites, basic extrusive rocks, marble, graywacke, dolomite, limestone, and other rocks, and have a total thickness of more than 15-17 km. The rocks are crumpled into meridional linear folds having longitudinal fractures. Devonian superimposed valleys, belonging to a group of late geosynclinal structures [31] and filled by formations

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[3]The Alaskan foredeep is described by the author in another work.

ery typical of such structures, constitute the upper structural stage upon this complex. This, in fact, is the zone of the caledonids at Spitsbergen.

The replacement of one type of section of the lower complexes by another is observable in a narrow, meridionally elongated zone, which L. A. Klitin quite reasonably considers a deep-seated fracture. Consequently, there arises a new example of a juncture of an ancient platform and a folded zone along a fore-deep (in the sense attributed to it by N. S. Shatskiy, [44]).

In the east, the Barents sea platform probably extends to the Severnaya Zemlya Islands [16], whereupon its edge turns southwest passing not far from the shores of Novaya Zemlya as evidenced by the Hercynian foredeep at its western littoral margin [12].

The northern boundary of the platform hardly extends far behind the continental slope zone, since within the limits of Nansen basin the floor manifests a sharply differentiated relief. On the basis of this indication and by virtue of the geophysical data it is more reasonable to assume that the structure here is folded rather than of the platform type. As a matter of fact, it has recently been revealed [40] that there is a sea mount whose summit is only 730 m below sea level, towering over the adjacent deeps for 3000 m between Franz Joseph's Land and the Pole.

Still another platform, apparently, is to be found in the northern Arctic. It is usually called the Eria platform ([1] and others). The contours of this platform are not yet shown on the map, since we have so far failed to gather the necessary geophysical materials. However, outcrops of its ancient basement and sedimentary mantle are revealed in northern Scotland. The geologic structure of this region was recently analyzed by Ye. V. Pavlovskiy (28 and 29]. It appears to us that the Eria platform also encompasses Iceland, the Faeroe Islands, and Jan Mayen, which are built up of very thick young extrusive formations.

Geologists interpret the tectonic nature of Iceland in different ways. The view expressed above, which is supported by R. Bemmelen [48], appears reasonable to us because similar volcanic complexes are widespread in Greenland. In particular, it is important to note their development in the Baffin Bay littoral of Greenland where they lie directly over the rocks of the shield and are also located within. This, of course, is but an indirect argument.

The Eria platform is separated from the Canadian shield (which also includes Greenland) by the Greenland-Newfoundland caledonids, just as it is bounded on the opposite side by the caledonids of Scotland and Scandinavia.

Thus, bearing in mind both the continental and submerged platforms, it is possible to say that a convergence of ancient platforms in the Arctic constitutes an important peculiarity of the tectonic pattern of the part of the earth sector under review.

2. ARCTIC FOLDED REGIONS

New data were recently supplied by V. S. Zhuravlyev and R. A. Grafov [17] in confirmation of the view that a zone of Baykalian folding extends over the northern part of the Russian platform. If one should speak of more recent folding, it might be possible to state that on the whole the age of folds becomes ever younger from the Atlantic to the Pacific Ocean.

The Caledonian folded zones extend along the periphery of the Atlantic. Extending through Scotland, Scandinavia, Spitsbergen, and further on to Newfoundland, the caledonids form a wide, but not very regular arc bulging towards the north. Typical Caledonian structure may be observed in each of the enumerated regions. In our case we shall restrict ourselves to a brief discussion of the caledonids of eastern Greenland.

Here, in the complex synclinorium of Eleonore Bay contiguous to Greenland Sea, sedimentary formations aggregating 15,000 m or more in thickness are developed [56]. Their main part is formed by strongly dislocated rocks of the Eleonore Bay complex which belongs to the Riphean (Greenlandian, [71]). They are represented by detrital rocks, including quartzite and slate, and also, particularly in the upper half of the section, by marble, limestone, dolomite, and marl, in places mottled of reddish. Overlying them is a formation of tillite (1000 m) and then a few series reportedly formed in shielded lagoons. The total thickness of the Riphean deposits amounts here to 12 km.

Transgressively and discordantly lying over the Riphean rocks are terrigenous carbonate deposits (about 1000 m) of Cambrian age followed by predominantly limestone formations (up to 2000 m) of Ordovician age. The Caledonian folding has caused a considerable metamorphism of the sedimentary complexes, in places to the gneiss stage, and was accompanied by granitoid intrusion. Devonian deposits already fill the internal late geosynclinal depressions and are composed mainly of continental series which in spots are several thousand meters thick [50]. Basaltic strata are to be found among these series.

The east Greenland caledonids, as well as those of Spitsbergen or Scandinavia, are separated from the ancient platform by a narrow zone constituting a typical foredeep extending for more than 1300 km. The examples of Spitsbergen and

Greenland, therefore, serve as a fresh confirmation of the conclusion that zones of Caledonian folding are sutured to the ancient platforms by means of foredeeps [32, 37].

The mountainous zone of the northern part of Peary Land is sometimes also assigned to the caledonids (in particular, by some Danish geologists). These views, however, require some comments. In the greater part of this mountainous zone the sedimentary complex is represented mainly by weakly metamorphosed [52, 54] arenaceous and argillaceous slaty rocks, about 4000 m in over-all thickness, contorted into large straight folds showing a northerly dip towards the northernmost tip of Peary Land. The upper strata of this complex belong to the Ludlow stage, those located lower are considered lower Paleozoic. The sedimentary rocks are cut ·through by minor dikes of dolerite and porphyrites. A comparison of the structure and development of the northern part of Peary Land with the caledonids of eastern Greenland and those of Spitsbergen reveals a considerable difference between them. In general, the evidence of geosynclinal development of Caledonian time at Peary Land is manifested weakly. However, phyllites and marbles, probably of considerable thickness, were disclosed at the northernmost extremity of the mountainous zone. But their age has not been determined. We believe these rocks to be Precambrian.

The structural formations of Peary Land are smoothly replaced to the west by the Paleozoic structures of Ellesmere Island, from which, as we shall presently see, they differ substantially. It seems that the folded structures of the northern part of Peary Land which are coupled with the main chain of Greenland caledonids, should be considered as the attenuation zone of the latter.

Such zones of attenuated folding may sometimes be encountered in the earth's crustal structure. Individual examples thereof could be found in the Arctic. There are well known cases where no distinct time boundaries are observed between foldings. However, in this case we are dealing with gradual structural changes in space, where the attenuation zones separate sectors of the earth's crust, qualitatively different because of their tectonic properties.

The Arctic region with primarily Hercynian folding occupies a vast area between the Russian and Siberian platforms. The Taymyr peninsula may conditionally also be included therein.

The tectonic development of Taymyr and the Severnaya Zemlya archipelago was complex [24, 34, 35]. Evidenced here are the tectonic movements of the Baykalian and Caledonian foldings with which one should associate definite geologic formations, but indications of the Hercynian phase of development are also manifested

clearly. Essential, in particular, is the fact that the injection of granitoid intrusions occurred towards the end of the Paleozoic as has been proved by absolute-age determinations for a number of intrusive rocks [9]. At the same time the Paleozoic geosynclinal processes developed in feeble form within the confines of the area in question. This is evidenced by the peculiarities of the geologic formations, the relatively low degree of metamorphism and deformation of rocks, and some other indications. Manifested in this case is again the transitional type of development between two structurally dissimilar regions: the hercynids (of the Uralian type) proper, and the Paleozoic structures of the Verkhoyansk-Chukchi region. In other words Taymyr is an example of the attenuation zone of Hercynian folding. This is the reason why its assignment to the hercynids is conditional.

Some investigators [58] consider the tectonic structures of the northern islands of the Canadian Arctic archipelago as belonging to the region of Hercynian folding. Reference is made to the folded belts of Ellesmere, Eureka, and Perry identified by I. Fortier, A. McNair, and R. Thorsteinson [53]. This classification appears to us as even more tentative than the example referred to above.

Study of the geologic structure of the islands[4] mentioned discloses a great similarity in the character of the Paleozoic deposits of these islands, Taimyr, and especially the mesozoids of the Soviet northeast. Most of the lower and middle Paleozoic geologic formations in all these territories are represented by rocks of the carbonaceous series, and not unfrequently also by halioc formations (see the chart of the geologic section relative to the central part of Ellesmere Island). The structural similarity of the above territories is also expressed in the same order of thicknesses of the respective deposits which attain high values (many kilometers), in the sameness of the tectonic forms which are moderately folded, and generally, in the moderate degree of metamorphism. Volcanics are weakly developed in the Paleozoic sections, or are almost absent. Thus, it is unquestionable that the tectonic development of the above territories up to the late Paleozoic was very similar. What then is the type of development?

On the occasion of a detailed inquiry into the peculiarities of the Paleozoic development in northeast Asia [31] I failed to detect a Paleozoic geosynclinal zone. I could not trace any indication of it in the geologic formations, in the magmatic manifestations, and finally, in the character of the folding or the metamorphism of the rocks in this vast territory. By the same token,

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[4]Particularly valuable in this respect is the book: Geology and Economic Minerals of Canada, 1957, edited by Stockwell.

Geologic Section of the Central Part of Ellesmere Island [58].

Age		Composition of Rocks	Thickness in feet	Location of sections
D	D_2-D_3	Sandstone, shale, coal seams	more than 10000	In the large syncline beginning at the eastern shores of Grinnell.
		Limestone, sandy limestone, sandy shale, and sandstone	1700-2900	
	D_2	Limestone, dolomite, calcerous shale, coral limestone	1900-3800	
	D_1-D_2	Calcareous shale	more than 1000	In the Druro Range region
S_2-D_1		Unfossiliferous sandstone	310	
		Dolomite	500	
S_2		Limestone streaked with shale	1300	
O_2-S		Predominantly dolomite	3700	
O	O_2	Limestone	4400	In the region of Copes Bay
		Gypsum	850	
		Limestone and some dolomite	150	
	O_1?	Unfossiliferous limestone with gypsiferous beds in the lower part	4800	
Cm_2		Limestone with subordinate shale beds	870	
Pt		—	—	—

neither can the tectonic conditions which prevailed here in the Paleozoic era be considered as characteristic of platform formation. In view of this fact, I have advanced a hypothesis suggesting that, apart from geosynclinal systems (or zones) and platforms as such, there exist special tectonic features termed mobile platforms. It is well known that we refer only to such territories as zones, any type of folding in which the features of geosynclinal development are definitely prominent (as a result of an analysis of the geologic formations, magmatism and dislocations). For a geosynclinal zone[5] indications of eugeosynclinal development are mandatory. In the absence of such indications over large territories, which in addition to their vastness are also structurally complex, difficulties are bound to arise. From our standpoint, the tectonic structures of the Canadian Arctic archipelago also present an example of a Paleozoic mobile platform.

In order to avoid confusion it should be noted that metamorphic and volcanic rocks are known to be located at the extreme north end of Ellesmere Island. These, in the first place, are rocks belonging to the, so-called, "Cape Columbia group" and partly to the "McClintock group". The outcrops of these rocks are located far apart, the age is unfixed and their interrelationship remains unclear.

Cited among the Cape Columbia group rocks [58] are gneiss, slate, quartzite, crystalline limestone, intruded by granite, peridotite, and syenite. Such rocks occur in the form of pebbles in Ordovician deposits. The age of the Cape Columbia group rocks is, probably, Precambrian and it therefore appears that they form a ledge of the ancient bedrock.

The McClintock group includes lava, breccia, tuff, tuffaceous graywacke, slate, sandstone, limestone, and an almost 400-feet thick gypsum layer. Similar rocks also occur in Ordovician rocks in the form of pabbles. Hence, generally speaking, either do these rocks represent stratigraphy analogues of the thick and predominantly carbonaceous deposits of the lower and middle Paleozoic at Ellesmere Island.

Widespread at the northeastern extremity of Ellesmere Island (also in the form of isolated outcrops) are primarily terrigenous deposits and, in addition to them, limestones of apparently mainly Paleozoic age: the Cape Rowson, Mount Disraeli, Sail Harbor, and View Creek strata. These facts justify the belief in the existence here of a transitional type of sequence between the sections characteristic of the northern part of Peary Land and the central part of Ellesmere Island.

The great similarity in geologic structure and tectonic development of the Paleozoic characteristic of the northern islands of Canada's Arctic archipelago and the northern part of the Asian mainland lends support to the assumption of the existence of a direct structural relationship

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[5]The term "geosynclinal zone" is used by us in the meaning attributed to it by N.S. Shatskiy [45].

between these territories. A natural geographic location for these links is the wide zone, with highly contrasting depths, of the ocean floor. This zone passes through the central part of the ocean and separates both submarine Arctic platforms. It is more than 1400 km long, and is half that in width. The zone is characterized not only by sharp differentiation, but also by the linearity of the elements of the ocean-floor relief which manifest a submeridional strike. However, near the islands of the Canadian archipelago there is a turn in these trends which complies harmoniously with the general strike of the archipelago's own structures. The zone discussed, moreover, is characterized also by peculiar geophysical data which are not typical of the adjacent submarine sections. The enumerated facts fully justify the assumption that this entire zone, judging by the tectonic nature of its Paleozoic formations, represents a mobile platform.

It, thus, appears that in those parts of the Arctic which are characterized by geographically continuous ancient platforms, no geosynclinal structures were formed in the early and middle Paleozoic. Rather, there formed mobile-platform type structures. It is through this fact that it becomes possible to explain the tectonic position of the latter.

Regions of Mesozoic folding in the Arctic occupy vast expanses of territory in northeast Asia and in the Pacific belt of North America.

Comparative tectonic studies of the mesozoids of northeast Asia and the Nevada belt in North America demonstrate their substantial difference. It consists in the fact that in the Nevadan belt, actually over the entire extent of its geosynclinal development, only the eugeosynclinal features are discernible, whereas no eugeosynclinal formations can be traced in the mesozoids of northeast Asia. This permits two types of mesozoids to be identified in the Pacific tectonic ring: the Nevadan and the Kolyman types.

In general lines, this breakdown is in accord with the views of H. Stille [78], who has subdivided the Nevadan belt into nevadids and Rockids (Rocky Mountains) in terms of historical development. Far greater thickness of deposits is characteristic of the nevadides (e. g., the Triassic and Jurassic formations of central Nevada are 10 km thick, whereas in the Rockies they represent only the few initial kilometers at the maximum). But the nevadides are particularly distinguishable from the Rockides by the abundant evidence of "initial volcanism", usually of basic type (though in places neutral, or even acidic).

The criteria on which H. Stille has based his system are fully valid for North America, as was proven by subsequent studies (McKay, for example). Yet, we are concerned with a far larger area, that of the Pacific belt. In this case we are primarily interested in the general type of structural development, and not in a detailed comparison based on the thickness of strata and some other concrete indices. In this sense our system appears to be more generalized and this justifies the introduction of new terminology.

The character of the deposits in the Koryak-skiye Ranges, as well as of Kamchatka and Japan [5, 39, 59] supports the belief that Nevadan-type structures form the base of the Kamchatkan (Cenozoic) folding. The zone of this folding extends along the extreme periphery of the Asiatic continent and over its offshore islands.[6]

It is generally known that the geosynclinal complex of northeast Asia's mesozoids, called the Verkhoyansk complex, is very peculiar. It consists of exceedingly thick terrigenous clastic strata formed during Permian, Triassic, and Jurassic time (including the Middle Jurassic). There are a great variety of opinions on their origin. It seems to us that the idea of large-scale development in the past of ancient shields in the Arctic, from which large masses of detrital materials might have been progressively carried away, sheds a new light on this problem and even suggests its general solution. It is possible that the small number of conglomerates to be found among the detrital rocks of the Verkhoyansk complex is attributable to the remoteness of the sedimentation area from the principal centers of erosive activity which were located much farther north. At the time when formative geosynclinal processes were becoming attenuated in the territory of the northeast Asia mesozoids, typical late-geosynclinal depressions and downwarps filled mainly by carbonous formations were formed.

Of great interest is the fact that there exists also in the Mesozoic stage, a certain analogy in tectonic structure and development between northeast Asia and the northern islands of the Canadian Arctic archipelago. Thus, on Ellesmere and Axel Heiberg Islands in the Eureka belt Triassic, and partly Permian, terrigenous clastic deposits very similar to the Verkhoyansk complex are developed. Dislocations in them are also approximately of the same type: simple and linear folds, sometimes box-shaped [53].

But is it possible to consider the Eureka belt as a zone of Mesozoic folding? This is a complicated question. The fact of the matter is that the area containing rocks equivalent to

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[6]These structures may also occur in the easternmost mesozoid zones. (S. M. Til'man).

Verkhoyansk complex is relatively small
he Canadian archipelago, and no granitoids
ch are characteristic for the Verkhoyansk-
ikotsk region were revealed therein. It,
refore, appears as if there was no basis to
tinguish an independent geosynclinal zone of
sozoids here. Yet, on the other hand, it is
ssible to assume that formations of Mesozoic
ding typical of northern Asia might have de-
oped locally within the limits of the Lomono-
' Ridge. In this case, the Eureka belt repre-
its the zone of mesozoid attenuation (as, in-
entally, is also the case for the southern part
Taymyr Peninsula). I think that this assump-
n is in better accord with the general struc-
al pattern of the Arctic. It is also clear
t this premise is not in conflict with the
sic tectonic principle that the mesozoids in
ir typical development are characteristic of
Pacific folded ring. Moreover, it empha-
es this regularity.

The younger Cenozoic folding is represented
atively insignificantly in Asia. It is dis-
rnible in the Koryakskiy chain in Asia and in
Coast Range in Alaska. The main portion of
s folding is to be found farther south.

3. ORIGIN OF THE ARCTIC OCEANIC BASINS

A general tectonic analysis of the Arctic leads
to a better understanding of the origin of its
eanic deeps. The basins of the Arctic Ocean
the present time may, indeed, be referred to
deeps, since tremendous depths, exceeding
00 or 4000 m were measured here. The geo-
ysical properties of the earth's crust in these
pressions are quite similar to those observ-
le in other oceanic regions.

In particular, J. Oliver, M. Ewing, and F.
ess [73], who were able to identify the sur-
ce seismic waves with unusually high ampli-
de (Lg waves) which are propagated only in
ctors of the earth's crust with continental
ructure, indicated that neither anywhere else,
or in the Arctic, has there been any reports of
ses of such waves passing at any appreciable
stance underwater deeper than 1000 fathoms
1820 m). Consequently, such sectors of the
rth's crust may not be considered as contin-
tal.

An attempt was made by R. M. Demenitskaya
0, 11] to calculate the thickness of the earth's
rust to the Mohorovicic discontinuity in the
rctic. For the central parts of Beaufort and
ansen basins, the resulting values were 5 to 7
n (from the ocean floor), and in their marginal
rts initially up to 15, and then up to 25 km.
the zone separating these basins the figures
ere somewhat higher, although at the Lomono-
v Ridge the crust was found to be only about
km thick in places.

Earlier, it was stated that in the territory
now occupied by the Arctic Ocean, over a con-
siderable period of geologic time, platforms
and other geologic features similar to those
which can be observed today on the continents
existed. Hence, it may be deduced that the
Arctic Ocean basin is a relatively recent, young
structure emerging on structures of continental
type, and in this sense is a secondary feature.
Such cases of the "oceanization" of continents
have become increasingly common at the present
time. The deeps of the Black, Caspian, Mediter-
ranean seas, the Sea of Japan, the Gulf of Mexico
and a number of other bodies of water have, ap-
parently, originated in the same manner [3, 25,
38, etc.].

Thus we concur with the conclusions arrived
at by many investigators of the Arctic basin: N.
S. Shatskiy [43], A. Eardley [19], D. I. Shcher-
bakov [46], D. G. Panov [30 et al.], V. N. Saks
[33] and other authors. As to H. Stille, in his
work published in 1948 [79], he has renounced
his originally identical views and began to con-
sider the Arctic Ocean a primary oceanic de-
pression.

A number of other considerations may be set
forth in support of our point of view concerning
the origin of the Arctic Ocean basin.

Noteworthy is the fact that the deeps of the
Arctic basin by their superficial area are
smaller than the shelf which extends for many
hundreds of kilometers over submerged Eurasian
territory. In this connection there arises a
question whether a grandiose gap in time could
be possible between the formation of the shelf
and the adjacent abyssal depressions which are
smaller in terms of occupied area?

On the other hand, the deep zones are, in
fact, very small in comparison with the sur-
rounding continental areas, and, therefore,
represent deep-sea sections of the Mediterranean
type rather than oceanic deeps [19, 46]. It may
be added that each of the deep trenches of the
Arctic basin is only twice the size of the Gulf of
Mexico and but slightly larger than the Sea of
Japan. The very recent origin of the deeps in
this sea (Quaternary period) may be considered
as entirely probable [20].

Finally, the exceptionally sharp relief of
Lomonosov Ridge, extending linearly and rising
steeply above the ocean floor to a height of
2500 to 3000 m, constitutes an important factor.
There are saddles on the ridge with the depth
over them ranging from 1500 to 1600 m, while
the minimum depths measured in 1954 amount
to 954 m [27]. The relief of the Lomonosov
Ridge is, therefore, characterized by shapes
similar to those of young mountain zones on dry
land. These shapes were, apparently, formed
in the same manner.

A variety of arguments in favor of the theory

concerning the secondary origin of the deeps in the Arctic Ocean were recently advanced by A. Eardley [19], author of the hypothesis relative to the so-called anicent Arctic formulated by him contrary to the opinions that there existed here for a constant oceanic basin.

When actually did the structural reconstruction of the earth's crust take place in the Arctic basin? Several hypotheses were proposed with this question in mind. From our point of view, the formation of the deep basins in the Arctic Ocean began in the second half of the Mesozoic. By this time gigantic tectonic and magmatic processes developed in the immense territories of northeast Asia and western North America. These processes were associated with the formation of the zones of Mesozoic folding and there formed, in particular, unusually large and diverse intracontinental depressions. The magmatic processes resulted in the saturation of the Mesozoic fold zones with granitoid intrusions which are commonly of enormous proportions. The formation of the Arctic basin deeps may be naturally related to all these phenomena.

Thus, from the example of the Arctic Ocean it may be seen that the earth's crustal structure characteristic of abyssal trenches, in particular, the insignificant thickness of the sialic layer, may be formed in the process of tectonic development of regions varying in origin and initial structure.

The mechanism of such reconstruction is not yet clear and various ideas have been expressed on the matter. For example, according to one group of hypotheses the subsidence of the earth's crustal blocks causes the sialic layer of the continental type either to dissolve or to melt [3, 25]. Sometimes this process is associated with an outflow of the sialic masses to the rims of the depression [25]. In J. Gilluly's opinion [61], the mechanism of this process is related to the thinning of the sialic layer under the influence of deep-seated changes ("subcrustal erosion") in the earth's mantle. R. Van Bemmelen [49] is inclined to search for the origin of this process in the basification of the sialic shield which tends to increase the weight of the blocks and is accompanied by their subsidence and "oceanization" of the structure. According to V. V. Tikhomirov [38], of principal significance in this process is the metasomatic effect of the transmagmatic solutions which infiltrate the substratum, and the basification phenomenon. It is possible that in reality there variety of processes occur.

From the position of modern theoretical tectonics it is possible to consider the formation of trenches in the Arctic Ocean as connected with the fracturing of the earth's crust. This seems to be evidenced also by the analysis of ocean floor morphology which exposes the major lineaments of the bottom relief with sharp contrasts in depth in some parts of the ocean relative to others.

Further investigation of ocean floor relief, a well as paleogeographic analyses and geophysic observations will bring us ever closer to an understanding of the most interesting problems posed by the geology of the Arctic.

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STRATIGRAPHY OF THE BASHKIRIAN STAGE[1]

by

G. D. Kireyeva, and I. I. Dalmatskaya

Since 1934, when S. V. Semikhatova succeeded in outlining the deposits of the Bashkirian stage in the Upper Carboniferous formations, the stratigraphy of this section has become the subject of careful scrutiny by a numer of investigators. Nevertheless, the problem of stratigraphic subdivision of the Bashkirian stage is not definitely solved, and the correlation of its sections from various regions is frequently difficult.

The authors of the present work have attempted a fractional subdivision of the Bashkirian stage deposits in the eastern part of the Russian platform through which several boreholes have been put. The surveyed stratigraphic subdivisions were compared with members previously identified by various investigators in a few other subdivided sections of the Bashkirian stage.

The lower boundary of the Bashkirian stage was initially substantiated by S. V. Semikhatova through the appearance of Choristites belonging to the group Choristites bisulcatiformis Semich. [14]. Somewhat later the Bashkirian deposits were subdivided by her into two parts on the basis of brachiopods [15]. In 1945, G. I. Teodorovich identified three stratigraphic members within the confines of the Bashkirian stage: the lower Bashkirian beds with Pseudostaffella antiqua (Dutk.), the middle Bashkirian beds with Choristites bisulcatiformis, Stafells conusa, Ozawainella, and the upper Bashkirian beds with thin-ribbed Choristites and Profusulinel. Teodorovich's lower Bashkirian formations were separated by G. D. Kireyeva [6] from the Bashkirian stage in the Perm district of the Ural region and compared with the Upper Namurian. In doing so she has considered the volume of the Bashkirian stage as conceived by S. V. Semikhatova in distinguishing two members in it which correspond approximately to the two upper Teodorovich members: the Bashkirian beds and the sub-Vereyan beds. The subdivision of the Bashkirian stage into two members was accomplished later on in a number of other provinces and adopted in a unified scheme [12].

A still more fractional breakdown of the Bashkirian stage is proposed for certain regions. For example, in the Donets basin, where S. V. Semikhatova (1936) and A. P. Rotay [13] correlated the following suites: C_2^1(F), C_2^2(G), C_2^3(H) and C_2^4(I), with the Bashkirian stage, G. D. Kireyeva [7] designates four stratigraphic units on the basis of fusulinids: the first member corresponding to suite C_2^1, the second to C_2^2; the third to C_2^3 and the lower part of the suite C_2^4, and the fourth to the upper part of suite C_2^4 (from limestone I_2).[2] A fractional breakdown of the Bashkirian stage deposits in the Donets basin is also provided by P. D. Potiyevskaya [8]. She has established biozones in it which embrace the following stratigraphic intervals (for limestones): F_1-G_1, G_1-H_5, H_5-I_3, and I_3-K_3.

The horizons of G. D. Kireyeva and the biozones of P. D. Potiyevskaya are identified on the basis of foraminiferal studies, and their characteristics are approximately the same (even though the boundaries do not coincide everywhere). The first zone is characterized by the presence of Pseudostaffella praegorskyi Raus., the second by Profusulinella primitiva Sosn. and Ozawainella beshevskensis Pot., the third by Ozawainella parahomboidalis Man., Profusulinella rhombiformis Brazhn. et Pot., the fourth by Eofusulina triangula (Raus. et Bel.). The first zone is compared by P. D. Potiyevskaya with the Lower Bashkirian, and the three upper zones with the Upper Bashkirian member of the unified scheme.

In one of his works, G. I. Teodorovich [22] proposes to subdivide the Lower Bashkirian strata into two parts. In the lower part he identifies a band of rocks characterized by the presence of corals Litvophyllum chernovi (Soshk.) var. antiqua Soshk. and determines the upper part of the Lower Bashkirian strata by the abundance of Choristites. The latter consideration induced S. V. Semikhatova [17] to assume that in this case G. I. Teodorovich conceives the

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Bashkirian stage within the scope of the unified scheme. In a major study devoted to a description of the Bashkirian stage in the right bank zone of the lower and middle Volga, S. V. Semikhatova objects to the separation of the lower Bashkirian member and holds to a two-member division of the Bashkirian stage [17].

In the same study, S. V. Semikhatova discusses the boundary between the Bashkirian and Moskovan stages. At her disposal she, regrettably, had the materials pertaining only to the southeastern part of Ul'yanovsk district. Consequently the list of foraminifera, which is conspicuous here for a number of local peculiarities, cannot be used for other provinces. As a doubtleddly local peculiarity of the section, Pseudostaffella and Eostaffella, which are abundantly represented in the Upper Bashkirian time, occur in the Vereyan member only in the form of isolated species.

In recent years, in a number of works not yet published in full, opinions have been expressed on the advisability of assigning to the Bashkirian stage, deposits which were previously considered as belonging to the upper half of the Namurian stage. This view is based on the fact that there exists a sharp difference between the faunal assemblages of the Lower and Upper Namurian, and on the similarity of the Lower-Namurian fauna to that of the Lower Carboniferous, and that of the Upper Namurian to the Middle Namurian fauna. Such a view on the scope of the Bashkirian stage is substantiated by the rosters of foraminifera and brachiopods, and in some cases of corals [1, 3, 4, 11].

This concept of the scope of the Bashkirian stage involves the incorporation into it of two members from below. The lower one of them is characterized by an assemblage of Eostaffela, Parastaffella, and Archeadiscus, and the upper one, by the appearance of the first pseudo-staffels (Pseudostaffella antiqua, Ps. compressa, and others). Ye. A. Reytlinger called them the Krasnaya-Polyana and Severnaya-Kel'tma members.

The brachiopods of the Bashkirian stage were studied by O. L. Eynor [24] from sections of the Perm district in the Ural region, while a parallel examination of the foraminifera was carried out by G. D. Kireyeva. As a result of the foraminiferal study four members were identified within these deposits (I, II, III, IV). These members are in satisfactory agreement with he distribution of brachiopods in the section. Members I and II correspond to the two presently discussed beds defined by D. Ye. Ayzenverg, N. Ye. Brazhnikova et al, and include the deposits which directly underlie the Bashkirian stage as evidenced in the unified scheme. Member III is characterized by the appearance of Profusulinella staffellaeformis, Pseudostaffella praegorskyi, Schubertella, and

spherical Parastaffella. It corresponds to the Bashkirian beds identified in the same region by G. D. Kireyeva in 1949, and to the member exposed by the Krasnaya-Polyana borehole in the Kama River region. Member IV is determined by the presence of Ozawainella pararhomboidalis Man. There appeared no deposits contiguous to the Vereyan member in the other sections in O. L. Eynor's materials. There is reason to believe that the upper part of the sub-Vereyan strata, which were recognized in 1949 in the Perm district of the Ural region by G. D. Kireyeva, and where large Pseudostaffella, the first Aljutovella, and rhombic Profsulinella are to be observed, may be considered as the V member of the Bashkirian stage.

In sharing the point of view on the advisability of expanding the scope of the Bashkirian stage, we are dealing in this work mainly with its middle and upper parts. Deposits of the two lower members of the Bashkirian stage which, according to the unified scheme, belong to the Upper Namurian, were registered only once in our material (Buzuluk borehole).

One of the most complete Bashkirian-stage sections is the one of the Ul'yanovsk borehole (Table). On the basis of foraminiferal determination it has become possible to breakdown the Bashkirian stage into Lower Bashkirian and Upper Bashkirian substages in the unified scheme. This subdivision is also borne out by the lithologic characteristics of the rocks in the section. The lower substage, just as in the left-bank sections of the Volga described by S. V. Semikhatova, is made up of carbonate rocks, whereas the upper substage contains a considerable admixture of terrigenous material.

The Lower Bashkirian substage deposits in Ul'yanovsk, identifiable within the 1123 to 1116 m interval, rest immediately upon the Protva member of the Lower Namurian. A description of the rocks encountered in the Ul'yanovsk borehole was prepared by L. M. Yelina. The Lower Bashkirian rocks are represented by yellowish-gray, gray, and light-gray limestones with green doak.

The foraminiferal complex determined here by Ye. A. Reytlinger contains: Bradyina cribrostomata Raus. et Reytl., Pseudostaffella antiqua (Dutk.), Ps. antiqua (Dutk.) var. gradis Shlyk. and Profusulinella staffellinella staffellaeformis Kir., as well as rare Archaediscus and Eostaffella.

In contrast with the lower, the Upper Bashkirian substage (1116 to 1097 m) is characterized by the presence of clay and sandstone, although limestone is also predominant here. Microscopic examination of the limestone disclosed that it are represented here by a variety of detrital and fragmental materials. Fragments of fossils and rocks are well rounded in certain

...es, aphanitic materials are rarely present.
...ins of glauconite and pyrite are encountered
...mestone. Predominant among detrital lime-
...es is the foraminiferal variety, but crinoidal
...brachiopodal limestones are also not in-
...quent. Of other organic remains, ostracoda
...fragments of bryozoa are evidenced, while
...algae are represented by Donozella which at
...es are abundant in the rock.

...I. Dalmatskaya has determined the following
...es of foraminifera in the Upper Bashkirian de-
...ts of Ul'yanovsk: Globivalvulina minima
...tl. (more commonly), Archediscus bash-
...cus Krest. et Teod., Eostaffella post-
...squensis var. acutiformis Krest. et Teod.,
...tafella postmosquensis Kir., R. exilis
...sd. et Leb., E. acuta Grosd. et. Leb., E.
...udostruvei var. angusta Kir., Millerella
...ilicata Kir., M. variabilis Raus., Novella
...nitiva Raus., Schubertella sp., Pseudostaf-
...a antiqua var. grandis Shlyk., Ozawainella
...bassensis Sosn., Oz. parahomboidalis Man.,
...astaffella bradyi (Moell), Profusulinella
...fellaeformis Kir. (commonly). The compo-
...on of this assemblage confirms the Bashkirian
...of the rocks involved.

...The described assemblage is characterized by
...nerous Archaediscus of the Archaediscus
...hkiricus group, by Eostaffella and pseudo-
...ffella of the Pseudostaffella antiqua phylum.
...r the first time there appear in the Bashkir-
...stage section Schubertel and Ozawainella of
...Ozawainella parahomboidalis type, which
...peculiar to the Upper Bashkirian member.
...e Profusulinella stafellaeformis type is com-
...n in the Upper Bashkirian deposits in Ul'yan-
...k, whereas in the Kama River horizon de-
...sits of the Lower Bashkirian substage, for
...ich it is characteristic in a number of other
...vinces, it is represented only in isolated
...es.

...The Upper Bashkirian substage in the Ul'yan-
...sk borehole may be subdivided into two parts:
...lower, characterized by numerous Archae-
...ci and Eostaffella, abundant Parastaffella,
...ofusulinel of the Profusulinella staffellaefor-
...s type, and singly appearing Ozawainella
...rarhomoidalis Man, and the upper where the
...nber of Archaedisci is sharply reduced, and
...ere Ozawainel are more frequently en-
...untered, with Ozawainella pararhomboidals
...ually being present among them. The absence
...Aljutovella and Verella, characteristic of the
...ber part, is apparently attributable to the
...perfectness of the core in consequence of
...ich it has not been possible to give a more
...nplete description of the upper part.

...The upper boundary of the Bashkirian stage
...the Ul'yanovsk borehole cannot be determined
...the basis of lithologic data. However, it is
...te clearly traceable by the fauna in view of
...appearance of masses of Pseudostaffella

irinovkensis Leont. (1096.88 to 1096.78 m in-
terval) and is found to occur at a depth of 1097
m. The Vereyan forms of Pseudostaffella
timanica Raus., Ps. cf. pseudoquadrata Man.,
Eostaffella mutabilis Raus., Aljutovella aljuto-
vica Raus. occur somewhat higher.

The full roster of foraminifera from the base
of the Vereyan member is as follows: Endothyra
bradyi Mikh., Eostaffella mutabilis Raus., Schu-
bertella obscura Lee et Chen., Sch. pauciseptata
Raus., Sch. cf. polymorpha Saf., Pseudostaffella
varsanofievae Raus., Ps. irinovkensis Leont.
(commonly), Ps. subquadrata Grosd. et Leb.,
Ps. timanica Raus., Profusulinella aff. staffel-
laeformis Kir., Pr. ? trisulcata (Thomp.), Pr.
ex. gr. ovata Raus., Pr. chernovi Raus. (com-
monly), Aljutovella fallax Raus., Al. subaljuto-
vica Saf. var. fragilis Leont., Al. aljutovica
(Raus), Al. artificialis Leont., Al. paraaljuto-
vica Saf., Al. dagmarae Saf.

This list evidences a considerable restoration
of the fauna on the basis of a great variety of
representatives of Profusulinella and Aljutovella,
the appearance of typical Vereyan forms of
Eostaffella mutabilis Raus., Schubertella
pauciseptate Raus., Sch. cf. polymorpha Saf.,
Pseudostaffella cf. pseudoquadrata Man., Al-
jutovella aljutovica Raus, and the forms of
Vereyan and Kashiran age, i. e., Profusulinella
subovata Saf., Pr. ? trisulcata (Thomp.), Pr.
chernovi Raus.

In noting the peculiarities of vertical develop-
ment of the Ul'yanovsk borehole fusulinid com-
plexes, one should emphasize that all the types
characteristic of the individual members are to
be encountered here in these beds fairly rarely
and attain their maximum development in the
subsequent member. This refers to types of
Prefusulinella staffellaeformis Kir., which
occur rarely in the Lower Bashkirian substage
of the Ul'yanovsk section, and frequently, in the
lower part of the Upper Bashkirian; to Ozawai-
nella pararhomboidalis Man. which is traceable
in the form of individual species in the lower
member of the Upper Bashkirian substage, and
fairly often in the upper member; and to Upper
Bashkirian Aljutovella which appears here from
the Vereyan bed.

In the Middle Carboniferous beds penetrated
by the Poretsk borehole, the presence of Bash-
kirian stage deposits could not have been pale-
ontologically substantiated owing to poor core
recovery. Nevertheless, we are inclined to
believe that this stage exists here by analogy
with the nearest hole at Prudy. Tentatively one
might assign to it these deposits located at a
depth of 658 to 666 m, represented by saccharo-
idal limestones with occasional streaks of dolo-
mite.

The first appearance of Middle Carboniferous
fusulinids in the Porechye region was registered

Middle Carboniferous

Bashkirian Stage

Substage	Unit	Characterization	1	2	3	4	5	6	7
Upper Bashkirian Substage	C_2^4(I)	Eofusulina triangula, rare Archaedisci, occasional first Aljutovels	Member V	First aljutovels, mass pseudostaffells, (Pseudostaffela latispiralis, etc.)	?	Melekessian member — First Aljutovella, abundant Pseudostaffella (Pseudostaffella krasnopolsky, etc.)	Melekessian member — No faunal assemblage. Identified by position in the section	Melekessian member — Eofusulina ex. gr. triangula, Verella sp., abundant Pseudostaffella irinovkensis var, ishimica	Upper Bashkirian undivided
	C_2^3(H)	Ozawainella pararhombodalis Profusulinella rhombiformis Archaedisci in masses	Member IV	Ozawainella pararhomboidalis		Cheremshanian member — Faunal assemblage unavailable. Identified According to position in the section	Cheremshanian member — Identified by position in the section	Cheremshanian member — Ozawainella pararhomboidalis	First Aljutovella, Verella, Profusulinella rhombiformis, abundant Archaedisci
	C_2^2(G)	Profusulinella primitiva and other rhombic profusulinels (tentative comparison)	Sub-Vereyan beds	First primitive Ozawainella and Profusulinella parva.		Upper Bashkirian	Upper Bashkirian	Upper Bashkirian	
Lower Bashkirian Substage	C_2^1(F)	Pseudostaffella praegorskyi, Archaedisci in masses	Member III — Kama River strata	Pseudostaffella praegorskyi, Profusulinella staffelaeformis, Schubertella	Pseudostaffella of the Ps. praegorskyi group Profusulinella cf. staffellae-formis, Schubertella				
	Upper part of C_1^5(E)	Pseudostaffella antiqua	Member II — Sever.–Kelt'ma strata	Pseudostaffella antiqua and other primitive Pseudostaffella					
	Lower parts of C_1^5(E) Upper parts of C_1^4(D)	Fine Eostaffella, parastaffella and Archardisci without Pseudostaffella	Member I — Krasnaya-Polyana strata	Fine Eostaffella, parastaffella and Archaedisci without Pseudostaffella					
Lower Bashkirian	Kama River member								Pseudostaffella antiqua and Ps. antiqua var. grandis (assemblage not characteristic)

Region	8	9	10
Moskovan	Melekessian member	First Aljutovalla and Verella Pseudostaffella irinovkensis var. ishimica — Melekessian member	Rare Archaedisci, Ozawainella pararhomboidalis (assemblage not typical) — Melekessian member
	Ozawainella pararhomboidalis, Archaedisci in masses — Cheremshanian member	Ozawainella pararhomboidalis, mass Archaedisci — Cheremshanian member	Cheremshanian member
Upper Bashkirian	Upper Bashkirian	Upper-Bashkirian	Undivided — Ozawainella pararhomboidalis Archaedisci in masses
	Diverse Pseudostaffella, Profusulinella staffiellaeformis — Kama River member	Archaedisci in masses, Bradvin and Climacammin	Upper-Bashkirian
Lower Bashkirian	Lower Bashkirian — Kama River member		
	Abundant Archaedisci and Eostaffella without Pseudostaffella — Krasnaya–Polyana member	First primitive Pseudostaffella, frequent Archaedisci and Eostaffella — Sever.–Kel'tma member	Diverse Eostaffella and abundant Archaedisci

Comparison of Fractional Subdivision According to the Foraminifera in the Sections of the Bashkirian Stage in Various Regions of European U.S.S.R.

1 – Donets basin (after N.Ye. Brazhnikova, 1951-57; G.D. Kireyeva, 1952; and P.D. Potiyevskaya, 1952). 2 – Permian Ural region (after G. D. Kireyeva, 1949 and 1954, and D.L. Eynor, 1954). 3 – Krasnaya-Polyana borehole (Ye.A. Reytlinger, 1954). 4 – Prudy borehole (I.I. Dalmatskaya and G.D. Kireyeva). 5 – Porechye borehole (I.I. Dalmatskaya and G.D. Kireyeva). 6 – Yulovo-Ishima borehole (D.M. Rauzer-Chernousova and I.I. Dalmatskaya, 1954). 7 – Kikino borehole (D.M. Rauzer-Chernousova and I.I. Dalmatskaya, 1954). 8 – Ul'yanovsk borehole (I.I. Dalmatskaya and G.D. Kireyeva). 9 – Melekess borehole (I.I. Dalmatskaya). 10 – Buzuluk borehole (I.I. Dalmatskaya).

at a depth of 658 m. The fusulinids encountered here are typical of the Vereyan member of Moskovan stage. At the base of these beds in the Poretsk region lies an 8-meter thick stratum of limestone overlain by brick-red clay. This limestone is mainly represented by detrital materials with rounded organic remains. The latter consist of foramifera, echinoderms, bryozoa, and less frequently of brachiopoda.

The complete list of foraminifera identified by I. I. Dalmatskaya in the carbonaceous stratum forming the base of the Vereyan member is as follows: Eostaffella mutabilis Raus. (frequently), E. exilis Grosd. et Leb., Schubertella obscura Lee et Chen., Sch. ex. gr. pauciseptate Raus., Sch. cf. polymorpha Saf., Pseudostaffella irinovkensis Putr. et Leont. (frequently), Ps. krasnopolskyi (Dutk.), Profusulinella convoluta (Lee et Chen.), Pr. ovata Raus., Pr. rhomboides Lee et Chen., Pr. chernovi Raus., Aljutovella lepida Leont. var. novoburasiensis Leont., Al. artificialis, Leont.

The typical forms of the Vereyan member are the mass Eostaffela mutabilis, Schubertella cf. polymorpha, Sch. ex. gr. pauciseptate, Pseudostaffella irinovkensis, and Aljutovella artificialis.

In passing over to the discussion of the Bashkirian stage in the Prudy region, it is worthwhile to note that very meager material was at our disposal, preventing us from giving a complete description of this stage.

According to L. M. Yelina's data (1953) there lies on the Protva horizon of the Lower Carboniferous in the Prudy region a 17-m thick stratum of motley-colored clays interstratified with thin layers of pink-gray limestone. In the lower part of the stratum, in the limestone bed located between the 746 and 743.92 m levels, I. I. Dalmatskaya succeeded in identifying the following foraminifera: Pseudostaffella compressa (Raus) (commonly represented), Ps. paracompressa Saf., Ps. korobezkikh Raus. et Saf., and Ps. varsanofievae Raus. (common). Types occurring both in the Bashkirian stage and in the Vereyan member of the Moskovan stage are encountered in this assemblage. However, predominant in it are the primitive Pseudostaffella of the Pseudostaffella compressa, Ps. paracompressa, and Ps. varsanofievae types, of which the two latter varieties are represented by relatively numerous specimens. Moveover, the Aljutovella registered here (Aljutovella fallax Raus, Al. cf. tikhonovichi Raus.) are common for the sub-Vereyan strata. This combination of primitive Pseudostaffella and Aljutovella in the

absence of typical representatives of the Vereyan bed justifies the belief that this assemblage belongs to the upper member of the Upper Bashkirian substage.

The first Vereyan fusulinids in the Prudy borehole area occur at a point 6 m higher than the location of the assemblage just discussed above. Determined here were: Schubertella obscura var. mosquensis Raus., Pseudostaffella krasnopolskiy (Dutk.), Aljutovella cybae Leont., Al. ex. gr. skelnevatica (Putr.), Eofusulina triangula (Raus. et Bel.).

This is not a large assemblage, but the Aljutovella and Eofusulina encountered therein evidence the Vereyan age of the rocks which bear them.

South of Prudy in the Penza district, the Bashkirian deposits were exposed in two boreholes: Kikino R-8 and Yulovo-Ishima R-4. The foraminifera from both holes were processed by D. M. Rauzer-Chernousova and I. I. Dalmatskaya [5]. According to these authors' data the Bashkirian stage at Kikino, which is 30 m thick, was initially broken down into two members, of which the lower one belongs to the Lower Bashkirian, and the upper one to the Upper Bashkirian substages.

The Kikino Lower Bashkirian substage contains a very poor uncharacteristic foraminiferal assemblage consisting of Archeadiscus, Eostaffella, and Pseudostaffella of the Pseudostaffella antique (Dutk.) and Ps. antiqua var. grandis Schlyk. types.

Unlike the Lower, the Upper Bashkirian substage contains the first Ozawainella (Ozawainella cf. pararhomboidalis Man., Oz. birinae Raus. et Dalm.), Aljutovella, and Verella. A more detailed breakdown could not be made owing to lack of material.

In the Yulovo-Ishima section, the Bashkirian stage is represented only by the Upper Bashkirian substage. After an additional analysis the latter was subdivided by us into two members: the lower cone contains, besides Archaediscus and Eostaffella, the characteristic Ozawainella pararhomboidalis. The upper bed contains eofusulinas of the Eofusulina triangula type and verels.

The easternmost points investigated were the sections of two boreholes at Melekess and Buzuluk [19, 20]. In Melekess the Bashkirian stage is represented by the Lower and Upper Bashkirian substages. The Lower Bashkirian substage with its mass of Archaediscus, Bradyina, and Climacammina, is delimited here by the Kama bed and contains: Archaediscus subbashkiricus Reytl., Arch. subbashkiricus var. grandis Reytl., Arch. postrugosus Reytl., Arch pseudomeolleri Reytl., Bradyina cribrostomata Raus. et Reytl., Pseudostaffella ex. gr. compressa (Raus), and other genera. On the basis of the changing foraminiferal assemblage the Upper

Bashkirian substage is subdivided into two members.

The lower member, with Ozawainella para-rhombodalis, contains the first Seminovella, Millerella, and Schubertella. Archaedisucs, and Eostaffella are frequently encountered. The first appearance of Ozawainella pararhomboidalis in this part of the section permits it to be compared with the sub-Vereyan layers of Krasnaya Polyana and the IV member in the Perm district of the Ural region [6]. Encountered here were: Archaediscus timanicus Reytl., Arch. postrugosus Reylt., Eostaffella varvariensis Brazhn. et Pot., E. exilis Grosd. et Leb., E. postmosquensis Kir., E. postmosquensis var. acutiformia Kir., Seminovella elegantula Raus., Ozawainella pararhombodalis Man, and other species.

The upper member differs from the lower by the presence of the first Profusulinella, Aljutovella, and Verella. This permits it to be identified with the V member of the Perm - Ural region [6]. Determined were: Profusulinella bona Grosd. et Leb., Pr. parva Lee at Chen., Pr. primitiva Sosn., Pr. staffellaeformis Kir., Pseudostaffella praegorskyi Raus., Aljutovella aff. elongata (Raus), Verella varsanofievae Dalm.

The boundary of the Upper Bashkirian substage and the Vereyan member is well defined through the appearance of typical Vereyan foraminifera of the type: Eostaffella mutabilis Raus., Schubertella borealis Raus., Aljutovella alutovica Raus., and others.

The completeness of the Bashkirian stage section in Buzuluk made it possible to identify in it the Lower Bashkirian substage with three paleontologically substantiated members which parallel the Krasnaya Polyana, Severnaya Kel'tma, and Kama River beds outlined by Ye. A. Reytlinger in Krasnaya Polyana, and the undifferentiated Upper Bashkirian substage with Ozawainella. No Verella and primitive Aljutovella were found in Buzuluk.

The lower member of the Lower Bashkirian substage is recognized in the Buzuluk borehole by I. I. Dalmatskaya on the basis of abundantly represented Archaediscus and Eostaffella without Pseudostaffella. This is characteristic of the Krasnaya Polyana beds: Archaediscus ex. gr. bashkiricus Krest et Teod., Arch. postrugosus Reytl., Arch. borealis Reytl., Arch. timanicus Reytl., Eostaffella postmosquensis Kir., E. prisca var. ovoidea Raus, E. postmosquensis var. acutiformis Kir., E. pseudostruvei var. chomatifera Kir., E. varvariensis var. umbonata Brazhn., Millerella uralica Kir., and other genera.

The middle member, Severnaya Kal'tma is conspicuous mainly through the appearance of primitive Pseudostaffella in the general assemblage of Archaediscus and Eostaffella of the Krasnaya Polyana variety: Archaediscus

rugosus Reytl. , Arch. timanicus Reytl. ,
h. donetzianus Sosn. , Arch. karreriformis
tl. , Eostaffella pseudostruvei var. angusta
. , E. protvae Raus. , Pseudostaffella com-
ssa Raus, and others.

The upper member of the Lower Bashkirian
stage, Kama River, is distinguishable by the
versified content of Pseudostaffella. This
peculiar characteristic in the faunal pattern
he Buzuluk strata (Pseudostaffella antiqua
itk.), Ps. sofronizkyi Saf. , Ps. paracompressa
. extensa Saf. , Ps. korobetzkikh Raus. et
, Ps. composita var. keltmica Raus.).

The majority of Archaediscus and Eostaffella
ur here from the underlying beds. A certain
uvenation occurs due to the appearance of
h forms as Archaediscus gregorii var.
egorii Dain. , Arch. visherensis Grosd. et
b. , E. parastruvei var. chussovensis Kir.

The Upper Bashkirian substage is typified by
appearance of Ozawainella pararhomboidalis,
presence of numerous bradyins, and numer-
s Archaediscus (Archaediscus pseudomoel-
i Reytl. , Arch. cf. borealis Reytl.), Pseudo-
ffella antique (Dutk.), Ps. antiqua var.
sterior Saf. , Ozawainella aff. birinae Raus.
Dalm. , and other genera.

The absence in Buzuluk of the foraminiferal
nal assemblage with the first Aljutovella and
rella is, apparently, attributable to the fact
at due to poor recovery of the core, the upper
rt of the Bashirian stage is apleontologically
sufficiently described. The boundary with the
ereyan member in Buzuluk is also undescribed.

A comparison of the investigated sections of
e Bashkirian stage with those in which a de-
iled subdivision was accomplished earlier (see
able) shows that it is possible to subdivide the
shkirian stage over a larger area in greater
etail than adopted in the unified scheme.

We believe that the stratigraphic subdivisions
cluded in the Bashkirian stage correspond in
gnificance to the members of other stages of
e Carboniferous, on the basis of their clear
unal description. In future discussion we re-
r to them as members and not beds.

As to the Lower Bashkirian substage, only
s upper member is present in the territory in-
estigated by us. The lower and the middle
embers, a brief description of which was
ven above, were recorded only in the Buzuluk
orehole. The upper member was traced in the
ikino, Ul'yanovsk, Melekess, and Buzuluk
oreholes.

Within the confines of the Upper Bashkirian
ibstage we identified two members: the lower,
r which the most characteristic form is Oza-
ainella pararhomboidalis Man. , and the upper,

the first Aljutovella and Verella. These mem-
bers were observed: the lower in Ul'yanosvk,
Yulovo-Ishima, Melekess' the upper in Ul'yano-
sky, Prudy, Yulovo-Ishima, and Melekess. Both
members have analogues in the previously
studied sections.

The lower, middle, and upper members of
the Lower Bashkirian substage correspond to
the Krasnaya-Polyana, Severnaya-Kel'tma, and
Kama beds of the Krasnaya Polyana borehole,
and to the I, II, and III members of the Perm
district in the Ural region. In the Donets basin,
the formations corresponding to the lower and
middle members are suits C_1^5, and to the upper:
suite C_2^1.

In the Perm district of the Ural region the
Upper Bashkirian substage members compare
well with the IV and V members. In Krasnaya
Polyana the sub-Vereyan beds correspond to
the entire Upper Bashkirian substage or only to
its lower part. As mentioned earlier, the upper
part of the Upper Bashkirian substage may, pos-
sibly, be absent in Krasnaya Polyana. In any
case, no faunal assemblage with Aljutovella and
Verellas is recorded here. However, the pos-
sibility is not to be excluded that both parts of
the Upper Bashkirian substage are represented
in Krasnaya Polyana by deposits with a uniform
foraminiferal fauna, in which Profusulinella
parva Lee et Chen. if typical.

In the Doneta basin two suites, C_2^2 and C_2^3,
correspond to the lower part of the Upper Bash-
kirian substage. Since each of them is char-
acterized by a foraminiferal faunal assemblage
inherent only to it (most typical for C_2^2 is Pro-
fusulinella of the Profusulinella primitiva Sosn.
group and various Ozawainella species; for
suite C_2^3, characteristic are Ozawainella para-
rhomboidals Man.[3] and Profusulinella rhombi-
formis Brazhn. et Pot.), it is possible to assume
that a local additional subdivision is recognizable
here at the base of the lower part of the Upper
Bashkirian substage. Corresponding to the upper
part of the Upper Bashkirian substage is suite
C_2^4 in which Eofusulina triangula (Raus. et Bel.)
becomes apparent. It was found in this member
in the Yulovo-Ishima borehole. The first single
Aljutovella may be found in the C_2^4 suite.

Thus, the Lower Bashkirian substage with
its three component stratigraphic members was
found in the Russian platform in Buzuluk apart
from Krasnaya Polyana. In the other sections

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[3] In M. F. Manukalova's work and in the recent study
of P. D. Potiyevskaya this form is considered as ap-
pearing in limestone H_4 and H_5. However, P.D.
Potiyevskaya, in her previous work, traced it in lime-
stone H_1. Its rare occurrence in the lower limestones
of suite C_2 is attributable to the lithologic peculiarities
of these limestones, in consequence of which foramini-
fera in them are in general very rare.

(Kikino, Ul'yanovsk, and Melekess) this sub-
stage is represented only by its upper member.
As stated earlier, the lower member is char-
acterized by an abundance of Archaediscus and
Eostaffella, the middle one, by the first Pseudo-
staffella, and the upper, by diverse Pseudostaf-
fella of the following types: Pseudostaffella
korobezkikh Raus. , Ps. sofroizkyi, Saf. and Ps.
praegorskyi Raus. together with Profusulinella
staffellaeformis Kir.

The Upper Bashkirian substage of the Bashkir-
ian stage may be considered as distinctly sub-
divided into two members. Simultaneously with
us they were traced in the Kama region by T. P.
Safonova. For the lower member we suggest
the name Chermshanian, with the section of
Staraya Utka region its type section being in the
Perm district of the Urals. The form most
characteristic for it is Ozawainella pararhom-
boidalis Man. , or for certain sections Profusuli-
nella of Profusulinella parva Lee et Chen. group.
The upper member we propose to call Melekes-
sian, the section of the main borehole in Mele-
kess serving as its type section [6]. Charac-
teristic here are the first Aljutovella, Verella,
and sometimes Eofusulina triangula (Raus. et
Bel.).

The Cheremshanian and Melekessian mem-
bers aggregatively correspond to that part of
the section which was described by G. D.
Kireyeva in 1949 under the name Vereyan beds.
This name is, therefore, no longer to be used.

In conclusion, we shall dwell on the question
pertaining to the substantiation of the boundaries
between the Bashkirian and Moskovan stages.
This work was completed by us only for the
sections of the Russian platform. The deposits
which correspond to the Vereyan member, in
the Donbass sections (suite C_2^5) contain a large
number of local types and their foraminiferal
assemblage differs sharply from the description
we gave to the sections of the Russian platform
studied by us.

We do not have at our disposal any new data
on the Vereyan member of the Permian Ural and
Trans-Volga regions. As to the investigated
boreholes from the eastern part of the Russian
platform, the appearance in the Melekessian
member of representatives of the Aljutovella
genus (characteristic of the lower beds of the
Moskovan stage) seems to indicate a closer
similarity between this member and the Vereyan.
Nevertheless, in spite of the survival in the
Vereyan member of the species characteristic of
the Melekessian member (Aljutovella tikhonovi-
chi Raus. , Al. fallax Raus. , Al. pseudoaljutovica
Raus. , Eofusulina triangula (Raus. et Bel.) and
other types), the boundary between the Bashkir-
ian and the Moskovan stages is traceable clearly
enough through the appearance of certain genera
unknown in the lower formations and sometimes
nonexistent at all above the boundary of the

Vereyan member. Among these genera one
should mention the following: Eostaffella muta-
bilis Raus. , Schubertella pauciseptate Raus. ,
Sch. polymorpha Saf. , Pseudostaffella pseudo-
quadrata Man. , Aljutovella aljutovica (Raus),
Al. skelnevatica Putr.

Apart from the difference in the fusulind as-
semblages which is due to the appearance of the
enumerated genera, a different quantitative
ratio of some other types should be noted in the
Vereyan member. Thus, Aljutovella tikhanovi-
chi Raus. and Al. fallax Raus. are considered
as common forms of the Melekessian member
and are seldomly encountered in the Vereyan
member. Pseudostaffella subquadrata Grosd.
et Bed, on the other hand, appears in the Mele-
kessian member only in the form of single
specimens, whereas for the Vereyan member
it is typical.

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LITHOLOGY AND STRATIGRAPHIC PROBLEMS
OF PRE-ORDOVICIAN DEPOSITS OF WESTERN VOLYNYA[1]

by

M. P. Kozhich-Zelenko, and P. L. Shul'ga

This paper presents a detailed breakdown of Cambrian deposits in the Valdayan and upper part of the Volynian series in western Volynya based on layer-by-layer mineralogic and petrographic study. The presence of Lower, Middle, and Upper Cambrian formations in the section is confirmed by spore analysis. Considerations on the relative position of the Cambrian lower boundary are expressed.

*   *   *   *   *

Pre-Ordovician deposits occur over the entire area of the Volynian and Podolian parts of the Russian platform. Their outcrops have long since been exposed in the Dnestr River region of Podoliya and in eastern Volynya. In recent years these deposits have been revealed by numerous borings in the Goryn' River basin and in the right bank areas of Zapadnyy Bug north of the Vladimir-Volynskiy latitude [2, 5, 7, 9, 10, etc.]. Further to the west, in the region of the L'vov-Lyublin downwarp or depression, these deposits are buried at a considerable depth. They are exposed only west of the Keletsko-Sandomir Ridge where they are fossiliferous.

In Volynya and Podoliya pre-Ordovician deposits are represented by terrigenous rocks almost entirely devoid of fossils. Only in recent years has it become possible to identify remnants of worms in them [10] and thereby to recognize the blue clay member of the Lower Cambrian among these formations in western Volynya.

The Middle and Upper Cambrian deposits also exposed here were identified on the basis of their stratigraphic position and by analogy with corresponding deposits in the Keletsko-Sandomir Ridge area [9]. Serving as the roof of the Upper Cambrian in western Volynya is the glauconite (Volkhovian) bed of the Lower Ordovician, which was deposited here transgressively on diverse Upper Cambrian strata. Below the fossiliferous deposits of positively Lower Cambrian age, a thick series of terrigenous formations with correlative extrusive rocks is now known to be buried in Volynya and Podoliya. There is a

variety of opinion on the stratigraphic classification and age of this formation. In Podoliya, these deposits have been long known as the Mogilev and Ushitsa suites [6], in the Goryn' River basin they were called the Ostrog series [12]. These were later broken down by A. V. Krasheninnikova [5] into Tashkovskaya, Gorbashevskaya, Izyaslavskaya, and Ushitskaya series. In western Volynya these deposits are referred to as the sub-extrusive, extrusive and sedimentary, and supra-extrusive strata [11]. In comparison with the stratigraphic subdivision of the corresponding deposits as adopted for the northwest and the western parts of the Russian platform, this series of controversial formations in Volynya and Podoliya on the whole corresponds to the Polessian, Volynian and Valdayan Riphean series.

The question of boundary delineation for the Lower Cambrian in the pre-Ordovician deposits of Volyniya and Podoliya is very debatable, as it is in fact for the entire Russian platform. Apart from this, the correlation of the individual stratigraphic subdivisions in pre-Ordovician formations throughout the area of Volynya and Podoliya proper, and with the corresponding deposits in the adjacent territories, presents a very complicated problem.

New data on the problems concerned relative to pre-Ordovician deposits of western Volynya has recently come to hand. On the basis of this information, it is possible to speak with greater confidence both about the age and the mineralogic and petrographic characteristics of these deposits. In a recently published article, P. L. Shul'ga and V. B. Shpakova [11] have furnished data on the new geologic section of pre-Ordovician deposits exposed by boring at Berezhtsy village, Lyublin district, Volynya province. The core was taken from a depth of 358.95 to 1220 m

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in these deposits which underlie a 13. 55 m thick Lower Carboniferous formation. Upon comparison of these data with the previously processed logs of pre-Ordovician deposits from neighboring boreholes, the authors classified them in Berezhtsy as possibly Cambrian (358. 95 to 879. 50 m interval) and Riphean (= Sinian, 879. 50 to 1220 m interval). Within the Cambrian, they identify the deposits of the Upper (358. 95 to 617. 20 m interval), Middle (617. 20 to 753. 65 m interval), and Lower (753. 65 to 879. 05 m interval) divisions. In the Riphean deposits a stratum was defined corresponding to Gdov and laminarite beds (879. 05 to 988. 25 m interval). Underlying it is a minor series of terrigenous rocks (up to 12 m thick) which gradually pass into volcanic tuffa (up to 60 m thick) overlying diabase which the drill failed to penetrate, having been stopped at a depth of 1220 m.

Taking advantage of the exceptionally complete log of the pre-Ordovician deposits recorded for the Berezhtsi borehole, because of the almost entirely recovered core, we have carried out a layer-by-layer analysis of the rocks composing these deposits from polished sections and fragments by the immersion method. The examinations were made by M. P. Kozhich-Zelenko, who in 1948-1949 studied the pre-Ordovician rocks from boreholes drilled in western Volynya. In confirming the division of the pre-Ordovician deposits exposed by the discussed Brezhitsy borehole just as this was presented by P. L. Shul'ga and V. B. Shpakova, M. P. Kozhich-Zelenko gives the following description of the mineralogic and petrographic composition of the series concerned.

An Upper Cambrian formation 258. 25 m thick consisting of sandstone and siltstone is located at a depth of 358. 95 to 617. 20 m. Its upper member (358. 95 to 441. 25 m interval) is made up mainly of light-gray, almost white, medium- and fine-grained quartzose sandstone accounting for 96. 4% of the thickness of the formation. At the top they are variegated, intercalated by siltstone, and have cross and undulating stratification. The middle member (441. 25 to 543 m interval) consists mostly of gray, greenish-gray, and dark-gray thinly laminated siltstone, which accounts for about 55% of the entire thickness of the member, and of streaks of sandstone. An alternation of thin layers of siltstone with finely-grained sandstone is also present. The rocks contain a large quantity of pyrite, and glauconite also occurs in places. The lower member (543 to 617. 20 m interval) is composed of light-gray, occasionally yellow, medium- and fine-grained quartzose sandstone with argillaceous cement.

The Upper Cambrian unit with its three members is conspicuous not only because of the predominance of one or another rock type, but also by its mineralogic composition (Figure 1).

The sandstone of the upper member (358. 95 to 441. 25 m), contains in its heavy fraction, considerable proportion of hydrogoethite (4 to 59%), ilmenite-magnetite (4 to 30%), leucoxene (12 to 31%). Of the heavy translucent minerals always present in large quantities are zircon (46 to 70%) and siderite (20 to 84%). Available in smaller amounts are such minerals as pyrite, garnet, tourmaline, rutile, anatase, brookite, titanite, epidote, chloritoid, mica, hyanite, and sillimanite. The light fraction is almost entirely represented (70 to 100%) by quartz with fissured, occasionally corroded, grains of angular and subangular shape. Of the thinly laminated minerals, kaolinite and hydromica were revealed. The presence of kaolinite and hydromica in the argillaceous fraction was confirmed by the method of coloration and by thermal analysis (See Figure 2, Sample 53). The analysis was carried out by A. M. Denisov in the laboratory of the Geological Institute of the Ukrainian Academy of Sciences.

The middle, siltstone, member of Upper Cambrian deposits (at a depth of 441. 25 to 543. 30 m) is characterized by the presence of large quantities of pyrite and hydrogoethite (46 to 83%), leucoxene (up to 28%), zircon (43 to 70%). Ilmenite-magnetite, garnet, tourmaline, rutile, anatase, brookite, titanite, epidote, spinel, chloritoid, mica, hyanite, sillimanite, and siderite were revealed in insignificant quantities in a heavy concentrate. Quartz predominates in the light fraction of the Middle series rocks, just as in the upper member. Also revealed were: feldspar (3 to 17%) and glauconite (2 to 17%). There is a somewhat greater proportion of micaceous and clayey minerals in the middle member (Figure 1).

The lower stratum of Upper Cambrian sandstone (depth: 543. 30 to 617. 20 m) resembles the upper stratum sandstone in mineralogic composition.

In comparing the lithological and mineralogic compositions of the Upper Cambrian rocks from the Berezhtsy borehole with deposits of the same age previously studied by us in the Turiysk region (Solovichi and Luchitse villages, suburbs of the city of Turiysk) we find a complete similarity between them. The only exception is that in the rocks of the Turiysk region (Volynian province) individual grains of hornblende were found which are not present in the rocks of the Lyuboml'skiy region. They turned out to be equally similar to the rocks, paleontologically defined as Precambrian, in the Keletsko-Sandomir ridge zone [3].

The lithologic character, textural and structural peculiarities of the Upper Cambrian rocks in western Volynya indicate that the deposition of a considerable part of or the entire series must have occurred in marine littoral conditions.

The presence among these deposits of continental formations is not to be excluded though.

is evidenced by the kaolinitic and hydro-
...ceous composition of the argillaceous
...tion of the component rocks. This is again
...ated by the predominantly arenaceous com-
...tion of the upper and lower members of the
...ation where no fossils have been found and
...th bears no signs of any organic life. Ac-
...ulation of the mentioned minerals was also
...ible under epigenetic conditions. Yet, this
...plicable only to the upper stratum of these
...sits which were subjected to corresponding
...ences in the continental interval which took
...e in this territory between the Cambrian
...the Ordovician.

...he series 130.80 m thick underlying the
...ussed Upper Cambrian deposits at a depth
...17.20 to 748.00 m,[2] and assigned by us to
...Middle Cambrian, consists of fine-grained,
...ly medium-grained green-gray and greenish
...t-gray quartzose sandstone. At the very top
...is formation, the sandstone is in places
...-brown in color and sometimes displays
...ss stratification. Siltstone bands are pre-
... The cement in the arenaceous rocks con-
... of greenish clayey mineral which forms oc-
...ional pockets, as a result of which the sand-
...ne appears mottled. The cement also in-
...les detrital mica, mostly biotite, although
...bonates are present, too. As in the over-
...g Upper Cambrian stratum, the mineralogic
...position of the heavy concentrate is char-
...erized here by considerable quantities of
...ite, hydrogoethite, zircon, occasionally
...rmaline, and by an insignificant proportion
...lmenite-magnetite with leucoxene, garnet,
...ile, apatite, siderite, anatase, and brookite.
...aracteristic of the rocks of the Middle Cam-
...an, particularly in its lower sections, is a
...ge quantity (up to 100% of the heavy fraction)
...lecayed hydrogoethitized mica. They were
...closed in the heavy and light fractions and
...e believed to represent the beginning and the
...d of the Middle Cambrian. As in the other
...posits, quartz also constitutes the predomin-
... mineral, whereas the feldspars are scarce.

In comparing the mineralogic composition of
... Middle Cambrian rocks from the Berezhtsy
...rehole with that of contemporaneous rocks
...eviously studied by us in other regions of
...stern Volynya, we must emphasize their
...milarity. In comparison to the Upper, the
...wer Cambrian is distinguishable by its poor
...nge in mineralogic composition. It lacks
...anite, sillimanite, glauconite, spinel, and
...anite which are contained in the rocks of the
...per Cambrian.

The relative assortment of Middle Cambrian
...ndstones, their frequently observable cross

stratification, poverty in range of mineralogic
content, absence of fossils, the kaolinitic and
hydromicaceous character of the argillaceous
fraction, as well as their uniformity throughout
the entire west Volynian area, justify the as-
sumption that they have accumulated on vast
alluvial plains and, possibly, partly along low-
lying sandy seashores.

The Lower Cambrian deposits (748.0 to
879.05 m interval) are represented mainly by
layers of siltstone alternating with sandstone
and argillite, with the exception of the lower
part of the formation which is made up almost
exclusively of sandstone.

The sandstones in the Lower Cambrian de-
posits are light gray to gray with a shade of
green, in grain size they range from fine and
medium to coarse. They are quartzose with
micaceous, argillaceous, and in places mica-
ceous, carbonaceous, argillaceous, cement. At
the bottom of the division (847 to 879.05 m in-
terval) they are cross-bedded, coarsely and
unevenly grained, and contain glauconite.

The siltstones are greenish-gray, gray, and
dark-gray with a greenish hue. At the top of
the division they are red-brown.

The argillites are gray and dark gray with a
shade of green, often bearing vestiges of fur-
rows made by worms.

The Lower Cambrian formation composition
may be divided into three strata on the basis of
its granulometric and mineralogic. The upper
stratum, 33.80 m thick (at a depth of 748 to
781.80 m) is characterized by psammitic silt
rocks with a large quantity of rusty-brown,
greenish, and decaying mica, and eroded fis-
sured anatase in the heavy concentrate. The
middle stratum 65.95 m thick (at a depth of
781.80 to 847.40 m) is characterized by pelitic
silt rocks with a high feldspar content and, with
mica in places. The lower stratum, 31.65 m
thick, (buried at 847.40 to 879.05 m) is char-
acterized by pelitic and psammitic rocks with
glauconite and in places with a greenish,
argillaceous mineral belonging to the montmoril-
lonite-nontronite group. A high proportion of
anatase, 25 to 28% of the heavy concentrate, was
revealed in these deposits. This mineral ap-
pears in the form of relatively large (up to
0.15 mm) and small tabular crystals.

The mineralogic composition of the Lower
Cambrian deposits is similar to that of the
Upper and Middle Cambrian. A heavy concen-
trate of these deposits revealed the following
minerals: pyrite, hydrogoethite, ilmenite-
magnetite, leucoxene, zircon, garnet, rutile,
tourmaline, apatite, barite, anatase, mica,
siderite, spinel, glauconite, montmorillonite-
nontronite. From this list of minerals found it
is apparent that the Lower Cambrian rocks

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[2] P.L. Shul'ga and V.B. Shpakova trace the
...oundary of the Middle Cambrian to a depth of
...53.65 m in this section.
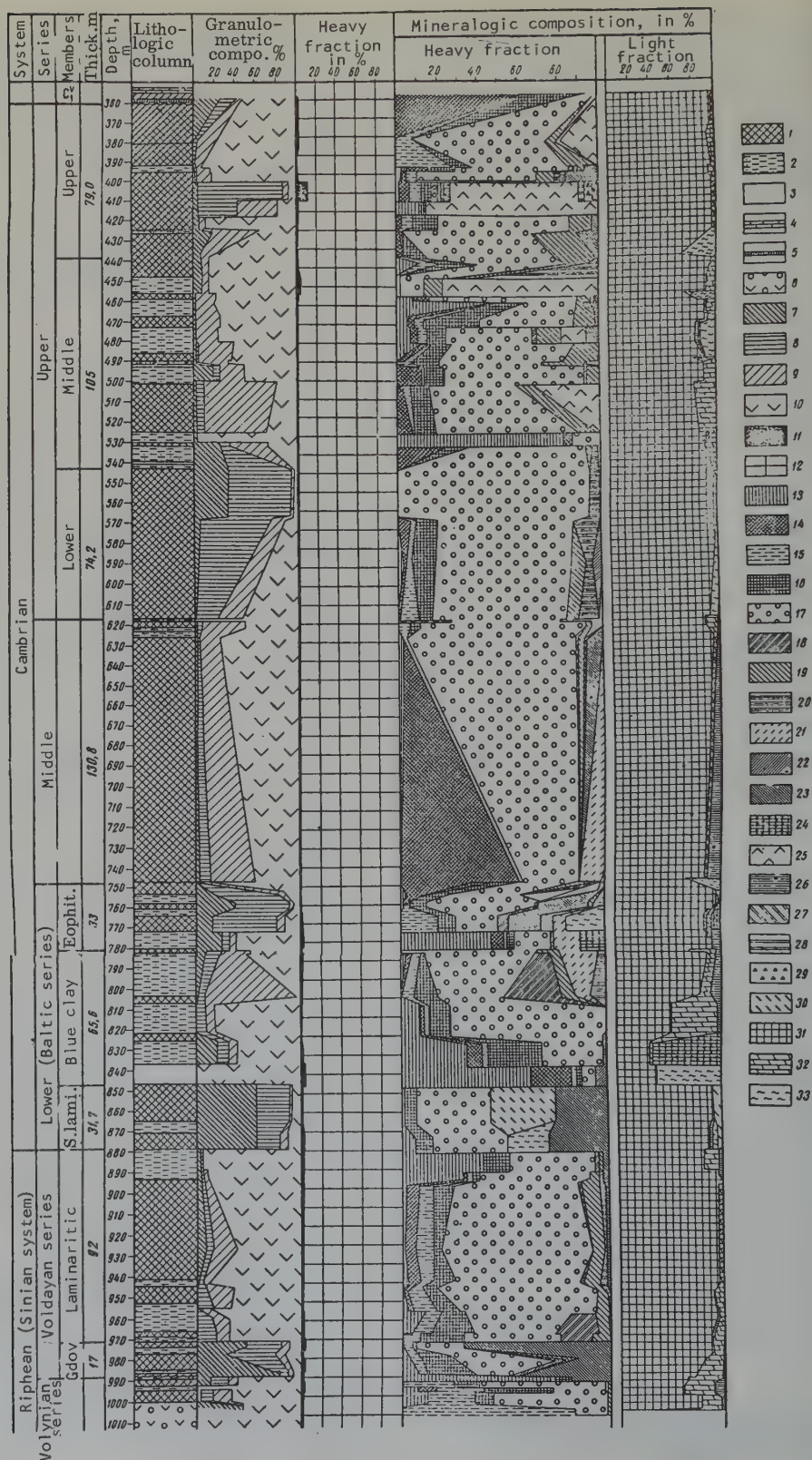
FIGURE 1. Lithologic characteristics of pre-Ordovician deposits exposed in the boring at Berezhtsy village, Lyubomol'skiy district, Volynian province

In lithologic column: 1 - sandstone; 2 - siltstone; 3 - argillite; 4 - limestone; 5 - carbonaceous shale; 6 - volcanic tuff.

In granulometric composition: 7 - fraction I (0.25 mm); 8 - fraction II (0.25 - 0.10 mm); 9 - fraction III (0.10 - 0.01 mm); 10 - fractions IV, V, VI (<0.01 mm).

In percentage ratio of the heavy fraction to the light fraction: 11 - heavy fraction; 12 - light fraction.

In mineralogic composition of the heavy fraction: 13 - pyrite; 14 - hydrogoethite; 15 - ilmenite and magnetite; 16 - leucoxene; 17 - zircon; 18 - garnet; 19 - rutile; 20 - tourmaline; 21 - apatite; 22 - brookite; 23 - anatase; 24 - magnezian carbonate; 25 - siderite; 26 - mica; 27 - sillimanite; 28 - kyanite; 29 - epidote; 30 - glauconite.

In the mineralogic composition of the light fraction: 31 - quartz; 32 - feldspar; 33 - clay minerals.

ain barite, which in places amounts to 39% he heavy fraction, and which was not found he Upper and Middle Cambrian. In the light tion quartz is predominant, though feldspar revealed in considerable proportion in the dle beds of the Lower Cambrian. The pre- ce of glauconite, magnesian carbonate, and ay mineral was also established (Figure 1).

A mineralogic composition of the Lower Cam- an rocks, in particular, the presence in them clay mineral belonging to the montmorillon- nontronite group, as well as the faunal re- ns, are evidence of their marine origin. The degree of decay registered in the minerals ated in the top section of the upper member of Lower Cambrian, and the variegated colora- of the component rocks, come as a definite ult of the effect produced on them by sub- ial agents. All this substantiates the theory cerning the existence of an interval in sedi- nt accumulation in western Volynia between Early and Middle Cambrian.

In concluding the lithologic description of mbrian deposits in western Volynya, one can- fail to note the uniformity in mineralogic nposition which is different in various strata, ntitatively and qualitatively, only under the luence of temporary variations in facies con- ions. The area of mineral alimentation re- ined unchanged in western Volynya for the ation of the entire Cambrian period. Judging all the available data, this alimentation took ce at the expense of the sedimentary deposits med by the products of erosion of igneous and etamorphic rocks of the Ukrainian crystalline ield.

The paleontalogic materials needed to deter- ne the age and correlate the western Volynya mbrian deposits with the corresponding de- sits in the adjacent or nearby territories still main relatively scarce. Yet, in comparison th the previously available data they have been nsiderably enriched. Up to the present time western Volynya, discoveries of worms were own only from the Lower division of the Cam- ian, while there was only one single find of nguella sp. in the Upper division [10]. To- y, results of spore analysis are available for
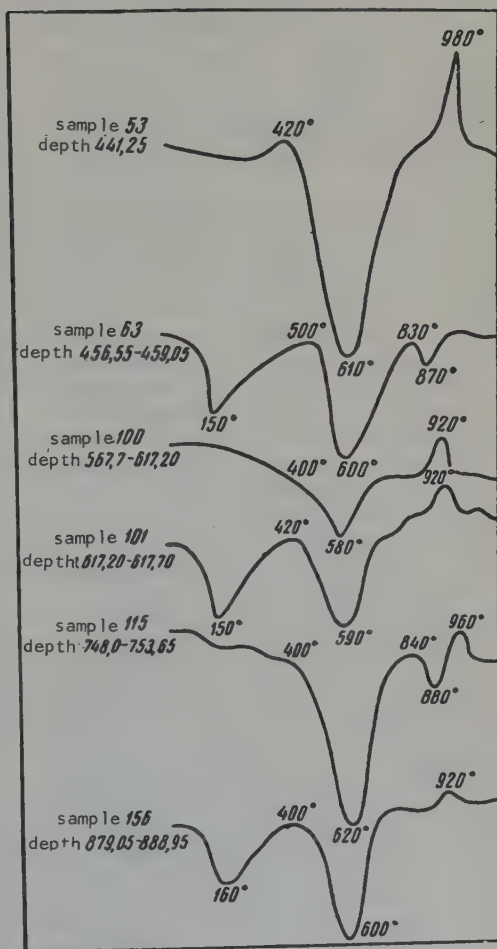
FIGURE 2. Thermal analysis curves for the Argil-laceous fraction of pre-Ordovician sandstone and siltstone from the borehole at Berezhtsy village.

Sample 53, kaolinite, depth: 441.25 m; sample 63, hydromica, depth: 456.55 to 459.05 m; sample 100, hydromica and kaolinite, depth: 567.70 to 617.20 m; sample 101 hydrocarbon with admixture of kao-linite, depth: 617.20 to 617.70 m; sample 115, kaolinite and hydromica, depth: 748.0 to 753.65 m; sample 156, hydromica with admixture of kaolinite, depth 879.05 to 888.95 m.

the entire Cambrian section at various points in western Volynya.

In core samples of the Upper Cambrian from a borehole at Rimachi village (Hole No. 404, depth locations, 340 and 404 m) B. V. Timofeyev discovered: Leioligotriletes crassus (Naum) Tim., L. nitidus Tim., Trachyologotriletes obsoletes (Naum), Tr. asperatus (Naum.) Tim., Tr. nevelensis Tim., Tr. minutus (Naum.) Tim., Lopholigotriletes sp., Acantholigotriletes setaceus Tim., Stenozonitriletes sp.

According to B. V. Timofeyev, the above assemblage of spores is unqeustionably Cambrian in age. Particularly emphasized is the presence therein of Acantholigotriletes setaceus, a genus described by B. V. Timofeyev from the obolous beds in the Baltic area. The deposits enclosing this spore assemblage are assigned by B. V. Timofeyev to the Upper Cambrian. In a way, he considers these deposits analogues of the obolous sandstone and dictyonemous shale beds of the Baltic.

Spores from the more complete Upper Cambrian section at Berezhtsy were studied from our samples by S. N. Naumova. The assemblage of these species, in her opinion, is absolutely identical to the assemblage of species from the paleontologically documented Upper Cambrian of the Keletsko-Sandomir zone. At the same time, it differs considerably from the assemblage of species in the obolous sandstone and dictyonemous shales of the Baltic.

Thus, the theory of the presence in the western Volynya Upper Cambrian deposits of correlatives of the Baltic obolous sandstone and dictyonemous shale beds has received no confirmation. According to T. N. Alikhova's data [1], the analogues of the latter should, apparently, be resting in the roof of the Upper Cambrian deposits. However, as mentioned earlier, lying in the roof of western Volynian Upper Cambrian deposits is the Volkhov bed of glauconitic sandstone which gradually passes upwards into limestone with numerous Endoceras sp., Asaphus sp., etc. The absolute-age determinations for this sandstone, based on our samples and carried out in the laboratory of the Geological Institute of the Soviet Academy of Sciences under the supervision of Prof. Ye. S. Burkser, showed 446 and 460 million years. These results have confirmed the correspondence of the western Volynian glauconitic sandstone to the Volkhov bed in the Baltic which constitutes the bottom formation of the Arenig stage there.

It follows from the aforesaid that an interruption in sediment accumulation took place in western Volynya at the Cambrian-Ordovician boundary corresponding to Tremadoc time. It may be surmized that in the Baltic this interruption corresponds to the member made up of obolous sandstone and dictyonemous shales, no age analogues of which, as previously stated,

were revealed in the Upper Cambrian of western Volynya. Neither are they known in the Upper Cambrian or in the Tremadoc in the Keletsko-Sandomir Range. It is true that the Tremadoc stage is incomplete here. Its lower parts are missing. This, according to J. Samsonowicz and M. Ksenrzkevicz [4] is due to a manifestation in this area of the Sandomir phase of the early Caledonian arogeny.

In the western Volynian Upper Cambrian deposits no paleontologic remains whatsoever were found until recently, even though searches, particularly for spores, were conducted many times. Spores were finally detected in Middle Cambrian beds in the previously mentioned two westernmost borings located in the villages of Rimachi (Hole 404) and Berezhtsy (Hole 2944). In core samples from Rimachi, taken at a depth of 449 m, B. V. Timofeyev has detected a large number of spores, among which he identified: Archaeohystricho spheridium Luberi Tim., Arch. sp. nov., Leioligotriletes minutissimus (Naum.) Tim., L. nitidus Tim., L. crassus (Naum.) Tim., Trachioligotriletes minutus (Naum) Tim., Tr. incrassatus (Naum.) Tim., Tr. obsoletes (Naum.) Tim., Tr. planus Tim., Tr. hyalinus (Naum.) Tim., Tr. asperatus (Naum.) Tim., Tr. nevelensis Tim., Tr. perlucidus Tim., Lopholigotriletes spatheformis Tim., Acantroligotriletes primigenus Tim. According to B. V. Timofeyev's conclusion the above spore assemblage is Middle Cambrian in age and very similar to the spore assemblage known from the Izhorski member in the Baltic.

In Middle Cambrian rocks drawn from the borehole in Berezhtsy village, spores were determined by S. N. Naumova from our samples. In her opinion this spore assemblage is perfectly identical to that from the paleontologically documented Middle Cambrian of the Keletsko-Sandomir Range. As to the spore assemblage from the Izhorski bed, S. N. Naumova finds its resemblance to the Volynian Middle Cambrian assemblage less distinct.

As mentioned earlier, numerous nuclei and imprints of worms were found in the Lower Cambrian in western Volynya. N. N. Yakovlev and T. N. Alikhova have identified the Platisolenites antiquissimus Eichw. and Serpulites petropolitanus Jan. which evidence the correspondence of the enclosing deposits to the blue clay bed of the Lower Cambrian in the Baltic.

In the Lower Cambrian core samples from Berezhtsi borehole, delivered by us to S. N. Naumova for analysis, the spore assemblage is identical to that of the Baltic blue clay bed, and to that contained in the paleontologically documented Lower Cambrian of the Keletsko-Sandomir Range. Only the spore assemblage from the lower sandstone stratum of the Lower

mbrian in Berezhtzi borehole presents an ex-
...tion. Its analogues could not be detected in
... Cambrian, Keletsko-Sandomir Range, where-
...in the western part of the Russian platform
...corresponding formation, judging by all
...ilable data, is the supra-laminarite member.
...e absolute age of the sandstones concerned,
...determined by glauconite from our samples
...he laboratory of the Geological Institute of
... Ukrainian Academy of Sciences, is 536
...llion years.

In summing up all that has been said concern-
...g the age and correlation of the Cambrian de-
...sits in western Volynya, it may be stated
...t included in them are paleontologically docu-
...nted sedimentary formations of the Lower,
...ddle, and Upper divisions. In lithologic
...aracteristics these divisions are similar to
...corresponding Cambrian divisions in the
...letsko-Sandomir Range, and by their spore
...semblage they are identical to those divisions.
...e Lower Cambrian of western Volynya, parti-
...arly in the eastern sections of this region,
...nologically resembles the Lower Cambrian of
...Baltic, and at the same time it does not dif-
...from the latter in terms of spore assem-
...age. In spite of a great resemblance in the
...nologic composition of the Middle Cambrian
...western Volynya and the Baltic, the spore
...semblage in these formations shows a con-
...derable difference. Correlatives of the
...olous sandstone and dictyonemous shale
...ratum do not exist in the Upper Cambrian of
...estern Volynya.

Let us pass over now to a description of
...dimentary formations assignable to the Riphean
...d located in the Berezhtsi village borehole be-
...w the sub-laminarite bed at a depth of 879.05
...1002.3 m.

The deposits from this interval are repre-
...nted by arenaceous argillaceous rocks, mainly
...ltstone and sandstone with micaceous, argil-
...ceous, and in places, calcareous cement.
...ree series are distinguishable quite distinctly
...these deposits by peculiarities in lithology.

The upper series, about 92 m thick, which
...es at a depth of 879.05 to 970.95 m is repre-
...nted by thinly interstratified greenish-gray
...ltstone and gray fine-grained sandstone. To
...ards the bottom of the series the sandy layers
...ecome predominant in the section. Films of
...rganic material are common along the strati-
...cation planes in this series.

The second, middle series located in the
...70.95 to 988.25 m interval is represented by
...ght-gray to white, kaolinized, uneven-,
...edium-, and coarse-grained feldspathic and
...uartzose sandstone with argillaceous, and, in
...laces, calcareous cement. The sandstones
...re mainly cross-bedded.

The third and lower stratum, lying at 988.25
to 1002.3 m is made up of greenish-gray, oc-
casionally dark-brown, highly micaceous silt-
stone and fine-grained sandstone. The rocks
are mostly thinly laminated. Towards the bottom
this series gradually merges with the underlying
volcanic tuffs with which is intercalated in the
interval between 1000.5 and 1002.3 m.

The three strata referred to above differ not
only in lithologic characteristics, but also in
granulometric and mineralogic composition
(Figure 1). Thus, a large quantity of coarse
grained material is concentrated in the second,
or middle stratum. The greatest proportion of
fine-grained material is to be found in the first,
or upper stratum.

The bottom, or third stratum or member
(depth: 988.25 to 1002.3 m) is characterized by
an exceptionally high content of ilmenite-
magnetite, up to 80% of the heavy fraction in its
bottom section. In the middle stratum the
ilmenite-magnetite content reaches up to 23% of
the same fraction, while in the upper series
(depth: 879.05 to 970.95 m) the same mineral
comprises no more than 2 to 10% of the heavy
fraction.

Leucoxene, a decay product of ilmenite, is to
be found in considerable quantity in all three
series, but its percentage drops appreciably in
the upper sections of the middle series. Yet, by
contrast, the proportion of authigenic anatase in-
creases here very noticeably. It appears in the
form of fine yellowish-brown tabular crystals
(Figure 3), originating obviously from leucoxene.
It seems that this series originally contained the
highest proportion of leucoxene and, perhaps,
also ilmenite.

Pyrite and hydrogoethite are present in all
three series, but occur in large quantities in the
upper parts of the first series.

Of the heavy-fraction translucent minerals,
zircon is to be found in large quantities in all
three series. It constitutes 20 to 79% of this
fraction. Zircon occurs in the form of color-
less elongated semi-rounded crystals, some-
times in the form of fissured fragments. It
contains rounded and semi-rounded inclusions.
The other minerals, such as garnet, rutile,
tourmaline, chloritoid, apatite, brookite, mica,
spinel, and carbonates were disclosed in in-
significant amounts.

The light-fraction composition also varies in
the three series under consideration. At the
bottom of the lowest, or third series, where
interstratification with volcanic tuffs is ob-
servable in the 1001.3 to 1002.3 m interval,
sandstone was located containing highly eroded
feldspar, microcline, which makes up 54% of
the light fraction. This indicates that the bottom
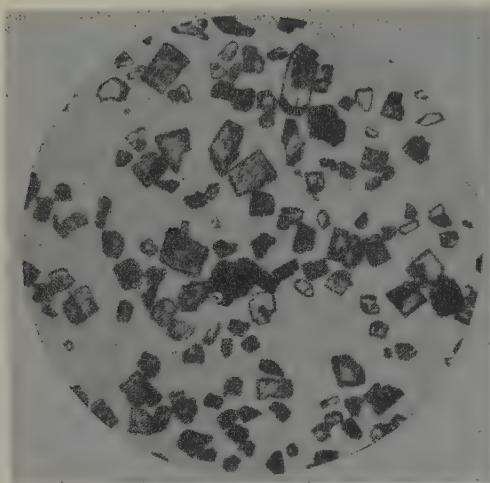sandstones in the lower series where they abut

FIGURE 3. Anatase

Borehole in Berezhtsy village. Depth:
977.65 to 986.50 m. Magnification:
70x.

upon the tuffs must have originally been of ex-
plicitly arkosic type. Upwards in the third se-
ries section, the proportion of feldspars drops
to 20 or 30% of the entire light fraction. This
fact permits these sandstones to be classified
as feldspathic.

In the middle series, the feldspars comprise
10 to 20% of the light fraction, with the exception
of the basaltic part of the section located be-
tween 986.5 and 988.2 m, where the feldspars
constitute 35% of the light fraction. The de-
creasing content of feldspars towards the top of
the second series may be attributed to their de-
composition, since the sandstones here are
highly kaolinized. Originally, these sandstones
seem to have been arkosic. In the uppermost,
first, series the feldspars are to be found in
insignificant quantities amounting to 3 to 10% of
the light fraction of the rocks. Here the sand-
stones are quartzose.

The mineralogic composition, as well as the
lithologic character of the three series dis-
cussed, evidence certain differences both in
provenance and in subsequent conditions of
transformation. For example, the high content
of ilmenite-magnetite and feldspars in the lower
series rocks suggests that extrusives have played
an important role in adding mineralogic types.
Thin stratification and relative assortment of
the rock material in this series indicates that
sedimentation must have taken place in a calm
body of water.

The predominantly uneven and coarse-grained
material of the middle series sandstones, which
originally must have been arkosic, as well as
the appearance in this series of garnet, indicate
that there were certain changes in sedimentation

compared to the lower series. False bedding,
and the poor assortment and rounding of the
material justify the belief that the rocks of the
middle series are the product of sedimentation
by relatively rapid streams which were acting
at moderately short distances from one another.
The basic provenance for source materials for
this series was, apparently, the local outcrops
of intrusive rocks which are in no way different
from those of the Ukrainian crystalline shield.
The upward growth of the decomposition pro-
ducts of various minerals (in particular, the
alteration of leucoxene) in this series must,
apparently, be considered a result of the in-
fluence of subaerial processes upon this series
after sedimentation. A pause in the accumula-
tion of sediments at the boundary of the middle
and upper strata may have been the cause of this
phenomenon.

The upper series, which extends right under
the supra-laminaritic bed, judging by its tin
grain, high measure of assortment, rounding,
and thin stratification, was formed by sediments
from an obviously quiescent and shallow body of
water. The presence of pyrite, particularly in
the upper section of this stratum, is evidence of
a reducing atmosphere in this body of water dur-
ing the deposition of the corresponding layers.
There exists a mineralogic affinity between the
upper and the middle series. Yet, the pre-
dominance of stable minerals (zircon, rutile,
tourmaline) in the heavy fraction composition of
the upper series rocks justifies the belief that
the material for this series was contributed by
the sedimentary series formed at the expense of
the rocks contained in the Ukrainian crystalline
shield.

The contact between the upper series and the
supra-laminaritic bed is very sharp in the
section investigated. Even the contact of the
middle and lower series is sharply outlined.
Less pronounced is the transition from the mid-
dle to the upper series and the gradual transition
from the tuffs to the lower series.

The age of the described sedimentary forma-
tions buried in Volynya and Podoliya under the
supra-laminaritic bed is a matter of discussion.
Some investigators assign it to the Cambrian.
The absence of any fossils whatsoever in these
deposits sets them apart from the richly fos-
siliferous Cambrian deposits located in the ad-
jacent region, the Keletsko-Sandomir Range.
Recently, an angular unconformity was dis-
covered there between the authenticated Lower
Cambrian formations with Holmia kiaerulfi
Lnrs. and the underlying more ancient, accord-
ing to J. Samsonowicz [4], Riphean deposits.
This unconformity in the platform seems to be
reflected in the investigated section at Berezhtsy
village by the sharply outlined contact between
the supra-laminaritic bed and the underlying
deposits. Taking all this into consideration, we
are inclined to trace the lower boundary of the

...mbrian along the bottom of the supra-lami-
...itic bed. The absolute age of the sandstones
...tained in the supra-laminaritic bed of west-
...n Volynya, which as mentioned earlier, is 536
...lion years, also speaks in favor of this solu-
...n.

...The first, or upper Riphean series which
...mediately underlies the supra-laminaritic bed
...similar to the laminaritic member of the Bal-
... This is favored both by the stratigraphic
...ition of the series and the lithologic composi-
..., as well as the textural peculiarities, of its
...mponent rocks. According to S. N. Naumova's
...l report, the spore assemblage in the series
...estigated at Berezhtsy village is identical to
...t from the lower half of the laminaritic bed in
... Baltic.

...The second, or the middle series is compared
...P. L. Shul'ga and V. B. Shpakova [11] superfi-
...lly to the Gdov bed in the Baltic. This com-
...rison must be considered very tentative.

...The age analogues of the third, or last series
...ich occurs, in the Berezhtsy log, directly
...er the volcanic tuff, and is associated with the
...ter by a gradual transition, are unknown in
... Baltic.

...Corresponding to the two series in question,
...ging by the available data, are the deposits
...the Ushitsa suite in the basin of the Goryn'
...Dnestr Rivers. The upper series corre-
...ponds to the lower part of the Kanilovskiy beds
...] of the above suite, while the middle series
...rresponds to the basal sandstone of the Kalyus-
...diy beds.[3] The incompleteness of the analogues
...the Kanilovskiy beds in the Berezhtsy section
... apparently, attributable to the erosion of
...eir upper parts. Part of the deposits contain-
...g lenses of phosphatized siltstones which are
...mmonly found in the upper half of the Kanilov-
...iy beds both in the basin of the Dnestr River
...d in that of Goryn' River was subjected to
...osion. The fact of such erosion is borne out
...the pebbles of phosphatized siltstone fre-
...ently found in the Lower Cambrian of western
...lynya.

...The incompleteness of the Kalyusskiy beds in
...e Berezhtsy section (it turned out that the
...alogues of the argillaceous beds of this unit,
...ich in the Dnestr area and in the Goryn' River
...sin contain globular concretions of radial
...rous phosphorite, are absent) is more prob-
...bly attributable to the fact that they were actu-
...ly not deposited here at all. The absence of
...twash products from the Kalyusskiy beds in
...e deposits overlying the middle series may
...rve as an indirect confirmation of this fact.

---

[3]Mereshovskiy beds, according to G. Kh. Diken-
...teyn.

The third, or lower series, with the under-
lying extrusive rocks in some respects cor-
responding to the Volynian series of the Goryn'
River basin.

The discussion contained in this article may
be reduced to the following basic postulates.

1. The Pre-Ordovician deposits in western
Volynya are represented by the Cambrian and
Riphean (= Sinian).

2. The Cambrian is represented here by
three divisions: the lower, middle, and upper,
which manifest peculiar features in mineralogic
composition, and have been described paleonto-
logically.

3. The Tiphean (= Sinian) deposits exposed
by boring in Berezhtsy village are represented
by sedimentary and extrusive formations be-
longing to the Volynian and Valdayan series.

4. The sedimentary sub-extrusive Riphean
formations consist of three units: upper, middle,
and lower, identifiable by peculiarities in their
lithologic and mineralogic composition. Of
these, the two upper units belong to the Valdayan
series, while the third, together with the under-
lying extrusive rocks, is assignable to the Volyn-
ian series.

5. A number of stratigraphic boundaries in
the investigated portion of the Pre-Ordovician
deposits in western Volynia bear distinct signs
of interruption of deposition accompanied by
erosion. Of these the principle (from the top
downwards) are: 1) on the boundary between the
Volynian and Valdayan series, 2) between the
Valdayan and the Baltic series.

Less important hiatuses are: 1) on the bound-
ary between the middle and the upper units of the
Valdayan series, 2) between the Lower and the
Upper Cambrian.

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BASIC GEOLOGIC PREMISES REGARDING
THE OIL AND GAS POTENTIALITIES OF UZBEKISTAN[1]

by

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The southeastern part of central Asia, as a
whole, and the territory of Uzbekistan, in
particular, have a long and very complex history
of geologic development. The closing phase of
the late Paleozoic era when geosynclinal pro-
cesses gave way to conditions conducive to the
formation of platforms, is an important divid-
ing line in this history. In consequence thereof,
a distinct boundary may be traced in Uzbekistan
between the folded basement and the Mesozoic-
Cenozoic sedimentary mantle.

The sequence in the folded basement is dif-
ferent here in many respects from that of the
sedimentary mantle. This is evidenced by the
dissimilar types of formations and their com-
ponent facies, by the varying degree of density
and character of metamorphism, the presence
of intrusive and extrusive formations in the
folded basement, the heterogeneity of local
geologic structures, and, finally, by the useful
minerals enclosed in them. If major bodies of
tungsten, polymetallic, copper-molybdenum,
and certain other ores are to be associated with
the deposits of the folded basement, then even
greater reserves of mineral resources of sedi-
mentary origin are to be found enclosed in the
rocks of the sedimentary mantle, namely:
natural gas, oil, sodium and potassium salts,
coal, as well as sulfur, celestite, and a few
other minerals.

These differences must, of course, be duly
taken into account in scientific research and in
exploratory and prospecting operations since
they are of paramount importance.

An effort is made in this article to shed some
light on the basic geologic indications of the
presence of gas and oil in Uzbekistan in con-
nection with the disclosure of oil deposits and
very large gas fields in its western regions.

THE MAIN HISTORICAL FEATURES IN THE
GEOLOGIC DEVELOPMENT OF UZBEKISTAN

Structural and facies analysis of the sedi-
mentary mantle favors the conclusion that in
post-Paleozoic time the southeastern part of
central Asia formed the southern periphery of
the vast Uralo-Siberian epi-Hercynian plateau.
In the early stages of its development, in the
Triassic period, sedimentation throughout this
territory occurred only in isolated areas (Fer-
gana valley). B. A. Petrushevskiy attributes
this to the fact that the leveling of the relief
formed as a result of Hercynian folding must
have occurred not in the Mesozoic, but earlier,
in the late Paleozoic [4]. In the Triassic the
young epi-Hercynian platform, as well as the
main part of Uzbekistan, remained stable and
raised and did not serve at that time as an
arena of energetic erosion, or that of powerful
sediment deposition.

Absence of Triassic sedimentary deposits
does not permit any definite conclusions to be
made on the structure of this territory at that
time. A zone of deep subsidence is more or
less distinctly traceable only in Dzhungariya,
at the southeastern extremity, since it is only
here that thick Triassic accumulations (in excess
of 2000 m) were revealed. Apart from the Fer-
gana valley, Triassic deposits in the central
Asiatic part of the epi-Hercyninan platform are
also known in Tadzhikistan. Here they are re-
presented by slaty arenaceous conglomerate
series of Rhaetian age. However, in the opinion
of B. A. Petrushevskiy, the main area of Triassic
deposits did not develop in the south Tadzhik de-
pression, but farther south, along the northern
slopes of the mountain ranges which today fringe
it on the south.

All this induced B. A. Petrushevskiy to come
to the conclusion that the territory in question
was structurally weakly differentiated in the
Triassic.

Nevertheless, theoretically one may also
speak of another area of development of Triassic
deposits. We have in mind the Pitnyak region of
the Amu-Dar'ya basin. In spite of all expectations

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based on the geologic study of the adjacent areas, in drilling a stable and a few prospect holes it was revealed that the thickness of the Cretaceous and the incompletely exposed Jurassic formations amounted to about 3500 m. Such considerable thickness with an almost 2000-m thinning at a distance of only some 60 or 70 km to the north (Meshekli) and further pinching out by almost 3000 m in the northwest (Sultan-Uiz-Dag) justify the belief that this area constituted a zone of uniform and protracted subsidence.

In comparing this fact with the facies characteristics of the Jurassic and Cretaceous formations, one may draw the conclusion that the character of these downbeddings is inherited and that they were, apparently, developing continuously since the late Paleozoic. If one is to consider a certain analogy in the structure and composition of the Jurassic deposits in the Pitnyak region and those of southern Emba valley, then one might assume that here, just as in the Emba region, variegated Triassic deposits occur at the base of the Mesozoic. This opinion was voiced by A. G. Babayev in 1953 and was more recently supported by L. G. Zhukovskiy and V. D. Il'in [3].

More distinctly traceable is the structural differentiation of the Jurassic period. Depressed zones, which became the areas of intensive sediment accumulation, were already formed by the beginning of the Jurassic. B. A. Petrushevskiy [4] feels that their development is associated with the deep faults which were formed back in the Paleozoic along the boundary of the heterogeneous structural complexes of the platform's folded basement which have reacted differently to the geologic events during the Mesozoic-Cenozoic stage of the region's development.

Among such downwarps one should include the eastern and the southern Fergana troughs, the downwarp of the south Tadzhik depression, the Bukharo-Karshinak, the Tashkent, and the Chardzhou-Pitnyak troughs. In all these downwarps (the formation of which must, in all probability, be correlated with the Liassic) sedimentation had started with the initial stage (Lias) of continental gray-colored sandy clayish formations containing commercial deposits of coal. The Lower Jurassic deposits are the thickest in the east Fergana and Chadzhou-Pitnyak depressions. It is interesting to note that in spite of the substantially different thickness of the Lower Jurassic deposits in these downwarps, and the large distance separating them, a general uniformity in lithologic composition is characteristic of all of them.

As far as the Middle Jurassic formations are concerned, their position is different. Here it is no longer possible to speak of a uniform lithologic composition. One thing seems to be unquestionable though, and that is that during the Dogger all these depressions continued to

subside, yet with different rates. In the final count this has led to the formation of different types of facies, as mentioned earlier. This situation is most graphically manifested in the south Tadzhik and Bukhara-Karshi downwarps. Alongside the gray and red arenaceous-argillaceous formations, limestone beds of marine origin are also developed to a certain extent. In other depressions, sedimentation of continental formations only took place: gray-colored (Chardzhou-Pityak trough) or variegated (east and south Fergana, and Tashkent troughs).

Even more differentiated was the movement in the Late Jurassic. Regrettably, the history of geologic development during this period cannot be readily interpreted for many regions. For example, we are not yet confidently certain whether there are any Upper Jurassic formations in the Fergana depression and in a number of other areas.

Only one fact is sufficiently clear to us: cases of new subsidence of the crust coincided with the beginning of the Late Jurassic in the south Tad-, zhik and Bukharo-Karshinsk depressions. Moreover, these downward movements were greater in scope than the preceding ones and were responsible for the transgression of the sea across these areas. Hence, for the first time in the Mesozoic history of southeast central Asia there emerged a relatively large body of salt water in which limestone deposits began to accumulate, while sandstone and clay with layers of limestone formed along its shores. Such Upper Jurassic sections are to be found everywhere in the south Tadzhik and Bukharo-Karshinsk depressions. On the basis of faunal assemblages enclosed in them, these formations may be assigned to the Callovian-Oxfordian stages. In the upper part of the sequence carbonaceous formations give way to deposits of evaporites represented by a thick stratum of rock salt, gypsum and anhydrite, which is usually assigned to the Kimeridgian and Tithonian stages.

It is noteworthy that neither carbonaceous nor evaporite facies of the Upper Jurassic are found in other parts of southeast central Asia and the remaining regions of the Uralo-Siberian platform. This fact, as well as the unconformable relationship in many regions (for instance, in south Fergana) of Cretaceous deposits over Jurassic formations, served as possibly the main argument in favor of the view that the folding phase took place in the Malm or, in any case at the boundary of the Jurassic and Cretaceous. We subscribe to B. A. Petrushevskiy's opinion that this surmise is not sufficiently substantiated. To the arguments advanced [4] we wish to add two more. First of all, in the regions with a completely developed Mesozoic sequence, there is a lack of any signs of folding within the Upper Jurassic deposits, as well as between the Upper Jurassic and Cretaceous formations. Secondly, the dislocation pattern of the Jurassic deposits

coincides with that involving the Cretaceous formations. As to the slight structural disharmony which is to be observed in certain Fergana regions, this O. A. Ryzhkov has recently attributed to reasons other than that of the assumed folding phase.

The absence of Upper Jurassic deposits in a number of areas may, in our opinion, be explained not necessarily by a manifestation of a folding phase, but by the fact that apart from the areas of subsidence there also existed uplifted zones both within these areas and beyond their confines. These uplifted areas in their hereditary development caused the emergence of gently sloping rises which subsequently turned into zones of erosion. In addition to this, also the assumption of partial erosion affecting the Upper Jurassic deposits in the Cretaceous period is quite realistic. As we may see, sedimentation in the Jurassic followed, on the whole, approximately the same pattern in different parts of southeastern central Asia.

Another picture comes to light from historical analysis of the geologic development in this area during the Cretaceous period. At this time, the development of certain areas assumed a few specific features, as reflected also in the substantial differences among the types of facies belonging to the contemporaneous parts of the sequence. Nevertheless, it is possible to speak in terms of three successively changing stages in the history of geologic development throughout the Cretaceous period. These stages are traceable all over the southeastern part of central Asia. As a matter of fact, it is significant that each of these stages have become initially manifest in the south or in the west, and occurred in other parts of the area under review after a certain delay.

The first stage may, on the whole, be referred to as the stage of continental sedimentation. In the western part of the south Tadzhik depression, in the Bukharo-Karshinsk and Chardzhou-Pityak troughs the deposits pertaining to this stage are represented by a fairly thick series of reddish sandstone, siltstone and clay. The bottom of this series consists mainly of fine-pebble puddingstone, while in its middle section it contains beds of dolomite with marine fossils and occasional interlayers of gypsum. The age of this series is Valanginian-Aptian. Similar deposits form the beginning of the Cretaceous sequence in the Zervashan Valley, the Fergana and Tashkent depressions. But the section here is saturated somewhat more intensely with conglomerate, whereas beds of unquestionably marine origin are either absent (Zeravshan, Tashkent troughs), or isolated (Fergana trough).

It should be emphasized that if this continental series in the Bukharo-Karshinsk, south Tadzik, and Chardzhou-Pitnyak depressions began to

form as far back as the Valanginian time, in the other troughs it must have occurred later, probably, in the Albian [2, 5]. The process of continental sedimentation has come to a close also at different periods: in the first three regions, in the Aptian; in the remaining areas, in the Senoman.

The Albian age appears as a very important boundary for the entire southeast of central Asia. It ushers the beginning of considerable cycles of subsidence, which developed progressively later on. In spite of the regional character of these crustal saggings, they were manifested most clearly in the western part of the south Tadzhik depression, in the Bukharo-Karshinak, and Chardzhou-Pitnyak troughs. It is precisely into these areas that the sea has transgressed in the Albian. But if typical marine deposition began in these areas, there occurred only a more intensified accumulation of sediments in the remaining regions. At any rate, there was no replacement of continental sedimentation by marine. As shown by A. M. Gabril'yan and S. N. Simakov, the sea penetrated only occasionally into the Fergana and south Tadzhik depressions. It is by virtue of this fact that the Albian deposits are represented here by continental formations with isolated suites or beds of marine facies.

A similar pattern developed also in the Senoman stage. But a new intrusion of the sea occurred in the Lower Turonian caused by new sinkings of the crust even greater than those registered in the Albian. Thus normal conditions for marine sedimentation were established practically throughout the entire expanse of southeast central Asia. It must be stressed here that due to the Albian, and particularly the Early Turonian transgressions, there occurred not only a replacement of continental sedimentation by marine, but also an appreciable expansion of the zone of subaqueous sediment deposition, particularly noticeable in the Lower Turonian.

Consequently, the second stage is characterized by an intensified development of downwarpings which have finally resulted in the replacement of continental sedimentation by marine. This very important stage in the history of the area's geologic development continued up to the Early Turonian, when upheavals began to manifest themselves, weakly at first, Then with greater intensity. Periodically these upheavals alternated with downbuckling, and reached their full expression in the Danian age. It is then that the body of the sea which previously existed here was split into a number of isolated basins, while the zone of subaqueous sedimentation has emerged to a considerable extent from under the water surface and become dry land.

It should be emphasized that it is precisely

during this third stage that the maximum up-
heavals and the greatest incidents of crustal
subsidence in Mesozoic history have taken place.
The crustal saggings which occurred in Mae-
strichtian time turned out to be so considerable
that they gave rise to a new wave of trans-
gression. This caused not only all the central
Asian water bodies to unite, but involved their
merging with the Maestrichtian seas of the Cau-
casus and the south Russian platform and also
with the west Siberian seas through the Turgay
Valley.

In speaking of the third stage, one should
dwell for awhile on the character of the ter-
restrial movements which took place in the
Danian age. Indications of intensive upheavals
during thie period are clearly traceable not only
in central Asia but also far beyond it. In many
places, Tertiary deposits overlie eroded Cre-
taceous formations conformably or unconform-
ably. Just as frequently, sections display the
absence of the Danian and a part of the Lower
Paleogene layers. All this justifies the belief
that in these places we are not dealing simply
with intensive upward movements, but, ap-
parently, also with folding movements which,
as in our earlier works [1, 2], we are apt to
correlate with the Laramide folding.

This, in general lines, is the Mesozoic his-
tory of the geologic development of Uzbekistan.
As we can see, each of the areas of subsidence
became more and more isolated with time as
independent zones of sedimentation. Yet, at the
same time there occurred a certain equaliza-
tion in the conditions of sedimentation during
the transition from the Jurassic to the Creta-
ceous.

The upheavals which marked the Danian age
have caused the single sea to split into a number
of totally, or partially isolated, water bodies of
the lagoon type (Ferganian, Zeravshanian, south
Uzbekistanian, and Bukharo-Karshinskian). The
subsequent subsidences of the Bukharian age re-
sulted in the intrusion of the Paleogene sea. This
has caused the isolated bodies of water to merge
again into a vast single basin, wherein various
types of carbonaceous and arenaceous-argil-
laceous (these to a somewhat lesser extent)
formations began to develop. These downward
morements seem to have been slow. They were
not, in any substantial measure, interrupted by
uplifts, and continued throughout the entire ter-
ritory of southeastern central Asia up to and
through the Eocene epoch.

A certain differentiation in movements is
traceable along the boundary of the Eocene and
Oligocene. At this time, uplifts began to appear
in the western regions of Uzbekistan, whereas
in the south Tadzhik, Fergana, Tashkent, and
partially in the Zeravshan depressions, the
downward movements continued. In view of
this fact, predominantly continental deposits

began to form in the western regions beginning
with the Oligocene, while marine sedimentation
persisted in the remaining areas until the end of
this epoch. It was only at the boundary of the
Oligocene and Miocene, or during the second
half of the Oligocene, that the sea was totally
dislodged from the territory of southeast central
Asia. This was caused by the mighty upheaval
of the Tyan'-Shan' mountain structure and the
associated discharge of vast quantities of detrital
materials into the zones of sedimentation,
whereupon thick strata of red-colored molasse
began to form.

Such, in a nutshell, is the history of geologic
development in southeast central Asia during the
Mesozoic and Cenozoic eras.

It is not difficult to identify in this history a
number of stages which are exceedingly import-
ant not only for purposes of general understand-
ing of the area's geology, but also in order to
comprehend the mechanism of oil and gas de-
position in the mantle formations of the Re-
public. Such stages are: the Upper Jurassic
epoch for the western and southern regions of
Uzbekistan (Chardzhou-Pitnyak, Bukharo-
Karshinsk, and Surkhan-Dar'ya depressions);
the Albian and Turonian ages for the same re-
gions and the Fergana valley; and the Paleogene
for the south Tadzhik and Fergana troughs. It
is precisely in the specified periods that the
particularly intensive and stable downwarpings
took place in the central Asian regions under
review. And it was then that favorable condi-
tions were created for the burial and subsequent
transformation of the initial organic matter into
hydrocarbons.

We believe that it is precisely in these parts
of Mesozoic and Cenozoic sections that the oil-
bearing formations are located. This point of
view is based on a detailed and meticulous
analysis of the ultimate composition of Meso-
zoic and Cenozoic deposits. It has been estab-
lished that precisely the Upper Jurassic, Albian,
and Lower Turonian strata in western Uzbeki-
stan, as well as the Upper Cretaceous and
Paleogene strata in southern Uzbekistan and in
the Fergana depression, were formed in a
marine basin in a reducing medium. It is
curious that just these sections are represented
either by dark-gray, green, or almost black
clays with rare interlayers of sand, sandstone,
and siltstone, or by limestone. It is exactly
with these formations that the traces of scat-
tered bitumens (tars, oils, and natural asphalt)
are associated. Finally, it is also highly signi-
ficant that all the presently disclosed principal
oil and gas deposits are enclosed either in these
formations, or in beds adjacent to them.

The following practical conclusion logically
suggests itself: one of the main criteria in de-
termining the zones favorable for launching
search and prospecting operations should be the

sclosure of aureoles of oil-bearing formations
in which one should look for sites suitable for
drilling.

A FEW STRUCTURAL PECULIARITIES

As previously noted, the southeastern part
of central Asia was a part of the vast Uralo-
Siberian epi-Hercynin platform in post-Paleo-
zoic time. By the beginning of the Mesozoic,
new structural formations began to develop in
the Uzbekistan area of this platform. By their
nature these formations, most probably, con-
stitute inherited tectonic elements. The Fer-
gana, Zeravshan, south Tadzhik, Tashkent,
Bukharo-Karshinsk, Chardzhou-Pitnyak, and the
south Aral depressions are to be considered as
such new formations.

These troughs differ from one another in the
time of their development, the type of facies
and formations making up the sequence of the
sedimentary mantle, their development features
and the degree of their mobility. Thus, the
Bukharo-Karshinsk, south Tadzhik, Chardzhou-
Pitnyak, and, apparently, also the south Aral
depressions may be envisioned as areas which
have experienced a uniform subsidence basically
uninterrupted by upheavals in the Mesozoic and
Cenozoic. The Fergana, Zerzvshan, and Tash-
kent depressions, on the other hand, must have
been at this time relatively consolidated zones
where crustal subsidence was less considerable
and repeatedly interrupted by upheavals of ap-
preciable proportions. These troughs differ
from one another also in their position within
the Ural and Tyan'-Shan' folded structure.

The platform-type of development charac-
teristic of the Tashkent, Fergana, Zeravshan,
Bukharo-Karshinsk, Chardzhou-Pitnyak, and,
possibly, the south Aral depressions is con-
firmed by numerous data. Far more compli-
cated is the problem of defining the structural
characteristics of the south Tadzhik depression.
The greater thickness of the sedimentary mantle
deposits than in the previously mentioned
troughs, the complex system of structural dis-
locations, the linearity in the location of struc-
tures and a few other characteristics of the
geologic structure of this depression, all sug-
gest that it should be considered a foredeep.
Yet, at the same time, the geologic structure
of the south Tadzhik area displays a certain de-
gree of similarity with the notable platform-
type region of western Uzbekistan.

Hence, the new structural formations in the
territory under review are heterogeneous in
terms of time of origin, history of geologic de-
velopment, and the characteristics of their
sedimentary formations. All this, of course,
calls for a different approach in evaluating their
oil and gas potentialities.

Let us examine somewhat closer the geo-
logic structure of the west Uzbekistan regions
which constitute one of the most important gas-
and oil-bearing provinces in the Union.

It was already said that western Uzbekistan
represents the southern peripheral part of the
Uralo-Siberian epi-Hercynin platform. The
important feature of development characteristic
of the platform is that the tectonic movements
here were quite independently of the tectonic
movements in the adjacent geosynclinal zone.
However, in no way does this indicate a lack of
correspondence in the trends of development of
the tectonic movements either in time or spa-
tially. In spite of an exceptionally distinct
boundary between the lower and upper structural
stages, considering the long interruption in sedi-
mentation processes after termination of the
Paleozoic cycle, the complex basement structure
is also reflected in the structure of the sedi-
mentary mantle. This is the reason why there
is a difference in the age, composition, and
depth of bedding of the ancient formations within
the confines of a single platform area. More-
over, this also accounts for the dissimilarity
in the types of sequences, facies, thickness,
and structural forms of the sedimentary mantle.
It will suffice to mention that whereas the thick-
ness of the sedimentary mantle at Kyzyl-Kumy
amounts barely to 100 m, it exceeds 4000 m in
the southern part of the Bukhara trough.

In the central and northern parts of the Buk-
hara depression, at Kyzyl-Kumy, and partially
along the upper reaches of Amu Dar'ya, the
local anticlines display a simple structure with
gently sloping limbs. By contrast, in the south-
eastern extremity of the territory, the Mesozoic
strata shows complex dislocations, the forma-
tions have a linear trend, and a highly asym-
metrical structure aggravated by upthrusts and
faults with an amplitude up to and in excess of
1000 m.

The geologic structure of west Uzbekistan
plain is characterized by two sharply pro-
nounced features.

In the first place, by a most complete strati-
graphic sequence of the sedimentary mantle in
the southern zones, and successive pinching out
of the facies as one approaches the northern
zones. If in the sections at the southern fringes
of the Bukhara depression, the Cretaceous de-
posits rest upon a complete sequence of Jurassic
formations, then the sections of the northern
periphery reveal Albian, with occasional Seno-
man, and even Turonian beds, at the base of the
sedimentary sequence. Such rejuvenation of the
sedimentary mantle occurs gradually. Thus, in
moving northwards one may observe an ever-
growing genetic discordance which, in turn, is
reflected in the varying aspects of the Creta-
ceous section.

In the second place, by variations in the strike of the anticlinal structures and their correlation. The formations which towards the northwestern limb of the anticlinorium formed by the southwestern spurs of the Gissar Range are distinguishable by a generally similar (linear) orientation. They have, apparently, emered under the influence of the horizontal component of gravity associated with the upheaval of the basement supporting the southwestern spurs of the Gissar mountains. Moreover, these formations are made more complex by faults with considerable displacement of beds and overturning of the southeastern limbs upon the northwestern.

Domes and narrow anticlines with quaquaversal bulges are the predominant structural forms characterizing the sedimentary mantle of western Uzbekistan. These uplifts coincide either with the tectonic lines of some other orientation (latitudinal: the Karshinsk group, northwestern: Pitnyak, Gazlinsk, or other groups), or they are arranged in en echelon pattern in relation to each other. Finally, they may assume the character of local rises totally independent from the neighboring uplifts (Kyzyl-Kumy).

It is interesting that the anticlinal folds extending along the southern periphery of the Zirabulak-Ziaetdinsk Mountains reveal no uniformity of strike whatsoever. They are structurally simple and must be considered as local vis-a-vis each other. This suggests that during the folding of the Mesozoic-Cenozoic series the Zirabulak-Ziaetdinsk Mountains played a passive role in comparison to that played by the southwestern spurs of the Gissar Mountains.

Many anticlinal formations are located northwest of Chardzhou Mountain along the banks of the Amu Dar'ya. According to the drill logs the sedimentary mantle at Tuya-Muyun and Sultan-Sandzhar exceeds 3000 m in thickness. Moreover, our investigations disclose that the Jurassic deposits are represented by the lower and middle members made up almost exclusively of sandy and clayey continental formations. The absence in these regions of Upper Jurassic deposits and of strata of marine origin in the Middle Jurassic indicates that there is a substantial difference in the history of geologic development of this area and the Bukhara depression. In the latter, the Upper Jurassic is represented by marine carbonaceous and lacustrine evaporite formations. In the Middle Jurassic, however, one may trace individual beds of limestones probably of marine origin. Bearing in mind the considerable total thickness of the Jurassic and Cretaceous deposits in the zone between Chardzhou and Pitnyak, as well as the absence of the Jurassic and some Cretaceous deposits in the adjacent northern areas, it is possible to assume that here we are dealing with an intracratonal depression of the syneclise type.

Back in 1953, in analyzing the character of

dislocations affecting the sedimentary formations filling this syncline, A. G. Babayev noticed a similarity in the structure, orientation, and dimensions of the anticlinal structures forming the Pinyak, Daraganati, and Kabakli groups. It was als o shown then that all the structures of these groups constitute local highs of the third order attributable to the major structure of the second order, and referred to by A. G. Babayev as the Amu-Dar'ya embankment. Later, the same uplifts were incorporated by V. D. Il'in and L. G. Zhukovskiy into a similar structure named the Darganati bench [3].

Among the local structures composing this bench one may point out a few sufficiently large ones, for example, the Sultan-Sandzhan, Kosha-Bulak, Tuya-Muyun, Meshekli formations and a few others, the dimensions of which range from 25 tó 30 x 10 to 15 km. In most places they display no fractures, yet some of them manifest a great deal of faulting, in particular, the Sultan-Sandzhar, Tuya-Muyun structures, and the Gazli group anticlines. It has been established that in spite of indications of the presence of oil and gas no commercial deposits were discovered in the first two of them. Yet, very considerable reserves of gas were found to be enclosed in the Turonian deposits of Gazli.

Since faulting has practically not been studied along the lower reaches of the Amu-Dar'ya, it is difficult to judge to what extent it could contribute to the formation of oil deposits, or, on the contrary, to their destruction. In a very general way one may only surmise, that in some cases this might have led to total degasification and disruption of oil and gas deposits (Tuya-Muyun, Sultan Sandzhar). In other cases, on the contrary, this may have been even conducive to the formation of tectonically shielded deposits. At any rate, it seems to be obvious that the presence of faulting cannot be construed as a good reason to minimize the oil and gas potentialities of the Mesozoic deposits along the lower reaches of the Amu-Dar'ya.

L. G. Zhukovskiy and V. D Il'in point out that still another bar is located north of the Amu-Dar'ya bench, which they have called the Bukhara bench. It trends almost parallelly to the Amu-Dar'ya bench. Moreover, attributable to its local structures are the deposits of gas, gas condensate, and oil exposed in very recent years (Setalan-Tepe, Dzhar-Kak, Karaul-Bazar, Sary-Tash, Gazli).

It is quite possible that the local high's of Kungur-Tau, Kassan-Tau, and Maymanchak-Tau are also forming a regional structure of the bench type. This guess though, of course, in a very general form, was made by L. Platonov back in 1926. If this is truly so, then one might recognize a third structure, the Karshi bench, within the bounds of the Bukhara depression.

Identification of such structural units as
nches in the territory of the west Uzbekistan
ains must play an important and positive role
t only for the understanding of this area's geo-
ic structure, but also in the disclosure of the
ll unknown gas and oil deposits. Search
erations and prospecting experience in other
atform areas (Aquitanian basin of France, the
l-bearing regions of West Germany and Hol-
nd, the Volga-Ural oil and gas bearing zone
the Russian platform, the mid-continental
l and gas bearing provinces of the U.S. and
on) bear witness to the fact that if such large
ructures as intracratonal depressions consti-
te zones favorable for the accumulation of the
itial organic matter and its subsequent trans-
rmation into hydrocarbons, then the benches,
ich complicate these structures and which in
rn break up into local formations, must serve
suitable traps wherein hydrocarbonic fluids
ually accumulate to form gas and oil deposits.

All the arguments in this discussion leave no
oubt that the structural conditions in the mantle
f west Uabekistan furnish the grounds for a
gh evaluation of the oil and gas potentialities
this vast territory.

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ON THE REGIONAL DEVELOPMENT OF LAUMONTITE
IN CRETACEOUS DEPOSITS OF LENA COAL BASIN[1]

by

A. S. Zaporozhtseva

Laumontite was first discovered in the western Verkhoyan Mountains by A. G. Kossovskaya [10] in Cretaceous deposits of the Sangary district, and in the region of Gradyga River, a tributary of the Aldan River. Subsequent investigations carried out by the author of this article in 1954 revealed that laumontitic cement in the vicinity of Sangary village is to be found mainly in the sandstones of coal-bearing Lower Cretaceous deposits of the Sangarian series in a 1200 m thick unit. In the coal benches proper, where layers of siltstone and argillite alternate with coal, no laumontitic cement has been encountered. It was not disclosed at the base of the series where kaolinite is observed in the cement of sandstones. Nor is it present in the underlying Jurassic carboniferous deposits which are characterized by other conditions of deposition and, consequently, by other authigenic materials.

Sandstone containing laumontite in their cement is highly developed in an area 900 km north of Sangary in the Lena delta region on the left bank of the Olenek channel in the Chay-Tumus coal deposits. It has become evident that sandstone with laumontite coincides here with definite strata and beds. The Chay-Tumus deposits are located in the area of development of the Olenek series. According to A. I. Gusev [6] this series, together with the underlying Lena series, constitute an analogue of the Sangarian series.

The section of these deposits reveals the following sequence: A 470 to 520 m thick Lukumay series rests at the bottom. It is represented by three sandstone beds 65, 130, and 120 m thick (counting from the bottom) intercalated with two thin (25 and 65 m) coal-bearing members. The sandstone beds, as suggested by their designation, are made up entirely by sandstone: medium- or fine-grained, predominantly quartz-feldspathic. The carboniferous beds, on the other hand, consist of rhythmically

alternating layers of fine-grained sandstone, siltstone, and coal. On the top of this series lies the carboniferous Uka series, 390 to 470 m in thickness, similar in composition to the carboniferous beds. The overlying formation is composed of the mighty sandstones (over 400 m thick) of the Meng-Yuryakh series, the composition of which is similar to the Lukumay sandstone.

The rocks in the sandstone members of the Lukumay and Meng-Yuryakh series contain a small quantity of quartz (32%), many potash feldspars and acid plagioclases (61%), a negligible content of micas, and acid, neutral, rarely basic, detrital extrusive rock-fragments. Concretions of quartz with plagioclase, quartz with epidote, quartz with epidote and muscovite, and plagioclase with epidote. The "heavy" minerals (according to 24 analyses of the Lukumay, and 24 analyses of Meng-Yuryakh rocks) are represented mainly by garnet (29-35%), epidote (50% in Lukumay and 35.8% in Meng-Yuryakh formations), sphene (5%), zircon (2.4%), apatite and ore minerals (5-11%). Prevalent among the latter are ilmenite and its alteration product, leucoxene. The heavy-fraction proportion is considerable (1.0 to 1.88%), and in occasional thin bands it is even very high, attaining 30 to 49%.

The sandstones are relatively tough. The terrigenous grains in them are closely packed, manifesting in places a superficial dissolution of the detrital grains, or granulation. Cement usually fills in the fine pores, its texture being perfectly identical to that contained in the Sangary-region sandstones, although the latter are considered older (lower part of the Sangarian series). In this region, as in the other, sandstones frequently display large concertions (0.30 to 0.80 m thick, 1.5 to 10.0 m long) constituting the same type of sandstone cemented by calcareous cement (corrosion cement). Judging by the character of pore-space filling, the cement texture in most sandstones is of the fringe type or basal. There are many zones where zeolite-laumontite or chlorite serve as basal cement. Sandstones with basal laumontite cement are light-colored (whitish), resembling

linized sandstone. Those with chloritic
ment are greenish-gray and contain a large
ntity of carbonized vegetable debris.

Both in Chay-Tumus and Sangary dense sand-
nes are predominant; they are light gray in
or with a greenish hue. In their pore cement
lite fills in the inner part of the pores, while
in chlorite film forms a peripheral fringe
ch in places is replaced by zeolite. There
sections in these sandstones where the
e hollows beyond the chloritic edge are
ed by zeolite. In other sections the infilling
thinly laminated, also authigenic, hydro-
aceous substance. Finally, there are sec-
ns in which the pores are filled with quartz,
more rarely with calcite. Now and then
grains of authigenic sphene may be found in
lite cement.

In terms of detrital minerals, the composi-
of the carboniferous sandstone beds in the
umay strata and the coal-bearing Uka
ies is of the same type. However, these
dstones differ from the rocks of the non-
boniferous sandstone beds of the Lukumay
Meng-Yuryakh formations. The sandstones
he coal-bearing deposits are represented by
re finely-grained varieties banded with silt-
ne, argillite, and coal. Among the rock-
ming detrital materials the proportion of
rtz (42%) in these sandstone beds increases,
le the content of potash feldspar and plagio-
se (51%) diminishes. The "heavy" fraction
o shows a decline (0.65 to 0.70%). Epidote
appears almost entirely (0.7%). According
he data of 49 analyses, its content ranges
m 0 to 2.3%. A drop is also to be registered
he amount of sphene (0.5%). The main part
he fraction consists of garnet (69.5%), zircon
7%), and highly altered limonite (1 to 4.5%)
ch accounts for the formation of leucoxene
1%) and the emergence of titaniferous min-
ls (9.1%). Fragmentary biotite, muscovite,
chlorite are present, but in negligible pro-
tions.

Authigenic materials, which cement the
dstones, are represented by kaolinite, sider-
(frequently oxidized), and to a lesser degree
calcite and hydromica. Chlorite appears
y at the base and the top section of the Uka
te. Observable also are aggregates of
niferous minerals, among which brookite,
atase, and rutile may be registered. Fine
1 to 0.25 mm) vegetable debris mineralized
pyrite are rarely encountered.

Siltstone contains the same fragmentary
terials, though displaying a greater pro-
rtion of mica and chlorite plates with biotite
them, considerably hydrated and carbonized
getable debris, as well as coal dust con-
tuting the invariable accessories. The argil-
es are composed of kaolinite and hydromica
d are dark gray in color. Often they contain

concretions or lenses enriched by siderite,
rarely by calcite, and to a lesser extent by
pyrite. They abound in some well-preserved
vegetable debris.

In the lower sections of the Meng-Yuryakh
series in the Chay-Tumus deposits, sandstones
with chloritic cement revealed concretions of
wood mineralized by zeolite. Such mineralized
wood (according to P. I. Glushinsky's oral re-
port) was repeatedly found farther northwest in
the Cretaceous deposits along the Olenek River.
However, in view of the fact that this zeolite
(laumontite) displays perfect cleavage in two
directions and a characteristic tendency to
split along these planes, it usually was mis-
taken for gypsum owing to its apparent softness.

One of such concretions constituting a min-
eralized tree trunk 4 to 6 cm in diameter was
penetrated by a borehole. Colorless, strongly
elongated (5 mm), thin and somewhat depressed
crystals of laumontite with a divergent orienta-
tion around a number of centers may be ob-
served in coaly material under the microscope.

Sometimes in polished section, the crystals
display a V-shaped form tapering towards the
center of the core. Cleavage is distinct, inter-
secting at a right angle. Simple and complex
twinning is to be observed. Rhombiform sec-
tions, sectoral extinction display regular inter-
growth of four individual crystals. The mineral
is biaxial, negative, $2V = 10\text{-}15°$; $\gamma = 1.517$
(± 0.002), $\beta = 1.516$ (± 0.002), $\alpha = 1.505\text{-}1.506$
(± 0.002), $\gamma - \alpha = 0.011$, oblique extinction $c\gamma = 40°$, elongation positive, although negative
elongation may also be noted. This mineral is
actually laumontite.

According to the data furnished by N. G.
Sumin [14] and G. V. Gvakhariya [4] refraction
in laumontite is subject to considerable fluctu-
ation: $\gamma = 1.527 - 1.517$; $\alpha = 1.514 - 1.509$,
while birefringerence is 0.013 to 0.011. The
same figures were reported for laumontite by
A. N. Winchell and H. Winchell [3].

M. N. Shkabara, in his dissertation in 1951
indicated that the refractive index for laumontite
is $\gamma = 1.517$, $\alpha = 1.504$.

L. K. Yakohontova [17] has determined that
the content of water in laumontite depends on the
medium in which it was preserved, and that the
optical properties of the mineral's crystals
change with increasing water content. Thus,
laumontite from Dashkesan, which was kept in
a dry environment, had $\gamma = 1.514 \pm 0.001$, $\alpha = 1.507$, $c\gamma = 37°$, whereas a sample which was
kept in moist conditions showed $\gamma = 1.527$,
$\alpha = 1.515$, with the extinction angle diminishing
thereby to 10 to 15°.

N. V. Rengarten [11] has determined the fol-
lowing constants for Malki laumontite: $2V = 44$ to

64°, $\gamma = 1.527$, $\alpha = 1.514$, $\gamma - \alpha = 0.013$, $c\gamma =$ 18 to 28°. She believes that this specimen contained MgO. These optical constants are closely approaching those of laumontite stored in damp conditions.

Laumontite contained in the cement of sandstone from both series of Chay-Tumus deposits is identical by its optical constants to laumontite extracted from the wood mineralized by zeolite.

In certain Chay-Tumus concretions the crystals of zeolite contain a coaly substance with fine calcite grains. In other sections, on the other hand, large (0.5 cm) transparent zeolite crystals extend through the petrified wood which contains a considerable amount of fine scattered grains of pyrite.

Samples of pure mineral without macroscopically observable inclusions of coaly material were taken from a calcium-free concretion. The data from a chemical analysis (Table 1) completed in the laboratory of the Institute of Arctic Geology shows that its composition is identical to laumontite.

effect that an increase in water content causes the mineral to become denser.

A. Ye. Fersman [16] believed the formula of laumontite to be as follows: $CaAl_2Si_4O_{12} \cdot 4H_2O$. H. Heritsch [18] was able to confirm this composition of laumontite unit cell by X-ray analysis.

Formula
$(Ca_{0.98}Na_{0.01}K_{0.01})_{1.00}Al_2Si_4O_{12} \cdot 3.7H_2O$
corresponds to the analysis referred to in Table 1. According to A. Ye. Fersman, laumontite is stable on the earth's surface, but it easily loses half of its water molecules and changes into secondary leonhardite ($Ca_2Al_4Si_8O_{24} \cdot 7H_2O$). Laumontite with a reduced amount of water was called β-leonhardite by N. I. Surgunov [15]. G. V. Gvarkhariya [4] fully concurs therewith.

M. N. Shkabara has translated the results of 68 analyses of various types of laumontite in terms of molecular quantities and came to the conclusion that depending on the thermodynamic conditions of formation, the crystal lattice may contain from 3 to 4.5 (from 11.44 to 16.19%) water molecules, and that the overwhelming majority of tests showed 3.5 molecules of

Table 1

Chemical Analysis of Laumontite (Sample 1097)
(as per published data)

Oxides	Fluctutations in oxide content in 15 tests		Laumontite content in a concretion taken from Chay-Tumus deposits (analyzed by A. Z. Shpindler)			
	from	to	wt. in %	wt. in %	Molecular quantity	Molecular ratio
SiO_2	50.76	52.45	52.07	51.85	862	4
Al_2O_3	21.40	23.92	21.84	21.75	214	1
Fe_2O_3	—	0.52	—	—	—	—
CaO	10.15	13.28	11.82	11.77	210	0.98
MgO	—	0.57	—	—	—	0.01
Na_2O	—	1.30	0.23	0.23	3.6	0.01
K_2O	—	0.03	0.25	0.25	3.6	0.01
$H_2O < 110°$	1.42	Single case 0.40 2.14 Single case 0.69	— 1.51	—	—	—
$H_2O > 110°$	11.44	12.89 Single case 14.18	12.70 100.42	14.15 100.000	786	3.7

(CaO, MgO, Na_2O, K_2O molecular ratios braced together = 1.0)

Chemical analysis of laumontite from Sangary shows a certain growth of Na_2O (0.71), a drop in CaO content (11.32), an increase in hygroscopic water (2.93), and a general rise in water content up to (14.60%). In comparison with the Chay-Tumus samples, this laumontite displayed a higher refractive index ($\gamma = 1.523$, $\alpha = 1.5.2$), but on the other hand a smaller extinction angle (20°). These data are in full accord with the conclusion drawn by L. K. Yakhontova to the

water. Laumontites formed at low temperature contain more water. The purely calcic varieties exhibit a higher water content than those in which calcium was partially replaced by sodium or potassium. He has also succeeded in showing that A. Ye. Fersman's secondary leonhardite [16], the leonhardite of N. I. Surgunova [15] and G. V. Gvakhariya [4], and the α-leonhardite of V. I. Vernadskiy [2] are alkalie-bearing laumontites.

A comparison of the analyses of laumontite
originating from Chay-Tumus with the known
analyses of calcic zeolites of the above authors,
as well as those of P. A. Zemyatchenskiy [8, 9],
M. Sumin [14], and M. N. Skabara, all of
which come from the Crimean and Caucasian
deposits, revealed the following facts. The min-
eral from the concretion in Chay-Tumus depos-
it constitutes, by its composition, a laumontite
with water content somewhat lower than theo-
retical (the sample from Sangary showed an
amount equal to theoretical) but higher than the
content registered in most types of laumontite.
The high proportion of water in Chay-Tumus and
Sangary laumontite is, apparently, attributable
to the low-temperature formation.

A sample of laumontite from another Chay-
Tumus concretion was also subjected to chemi-
cal analysis. This concretion contained calcite,
which dissolved in weak hydrochloric acid at
room temperatures, and coaly matter which could
not be separated. A calculation of the compo-
nents, without consideration of water and organic
matter, showed the mineral to be laumontite
with a higher content of Na$_2$O attaining 0.5%
caused by a drop in CaO percentage. However
its refractive index remained unchanged.
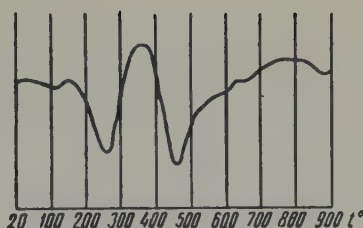
Figure 1. Thermal curve of
laumontite (Sample 1097)

In the laboratory of the All-Union Geological
Scientific-Research Institute, V. P. Ivanova has
constructed a differential thermal curve for
laumontite (Figure 1) and established its weight
losses as a result of heating (Figure 2, Table 3).

Experiments show that separation of water
stops over the range of 80 to 100° and even more
distinctly so at 240 to 300°. On the differential
curve, separation of the main portion of water
is accompanied by two distinct endothermal ef-
fects. Termination of water separation as a

Table 2

Spectrographic Analysis of Laumontite (contents in %)

Sample	Ba	Be	Cu	Cr	Fe	Ga	La	Mg	Mn	Sr	Ti	V	Zr	I	U
1097 pure laumontite	0.01	0.001	0.01	0.001	—	0.04	0.02	0.01	0.01	0.3	0.001	0.001	0.003	0.003	—
53 laumontite containing cal- ite and coaly material	0.01	—	0.01	0.001	0.3	0.02	0.02	0.01	0.01	0.3	0.040	0.003	0.003	—	0.003

The analyses were carried out at the Laboratory of the Scientific-Research Institute of Arctic
Geology under the supervision of R.S. Rubinovich.

A spectrographic analysis (Table 2) of the
mine samples revealed the presence of a con-
siderable amount of strontium, which is also
characteristic of some concretions from Chay-
Tumus deposits where strontium in places at-
tained 0. 1 to 0. 3%. According to G. V. Gvar-
liriya's data an increased percentage of stron-
tium, as well as barium, was observed in
another calcic zeolite, heulandite from Cau-
casian deposits, but was never registered for
laumontite.

result of heating is reflected by a pronounced
rise of the curve at 260 to 360° temperature.
The fact that water separates from laumontite
intermittently indicates its varying nature, i. e. ,
the presence of hygroscopic, zeolitic, and,
apparently, molecular water.

The powder pattern of sample 1097, register-
ed by N. V. Margolis at the Institute of Arctic
Geology (Table 4), shows that the investigated
material is a laumontite with a higher degree of

Figure 2. Loss of weight as a function of heating for laumontite (Sample 1097)

titaniferrous minerals. Their formation, as well as other processes developing in the silt, he is inclined to regard as a function of the biochemical changes taking place during the diagenetic stage.

In the Chay-Tumus deposits, laumontite penetrates the body of carbonized wood simultaneously with calcite and pyrite. These data seem to suggest that a reducing medium, though not with a small pH value, is favorable for the formation of laumontite. The fact that zeolites are not to be found together with kaolinite serves as another indication thereof. K. D. Glinka [5] observed long ago that it is impossible to obtain zeolites in the humus layers of the soil, and that the separation of zeolitic substances is most probable in alkaline land containing sodium.

crystallization than the sample from the American X-ray powder pattern photograph collection (X-RDC). From the laumontite sample described by Ye. Z. Bur'yanova [1] it differs by absence of calcite and quartz.

A confirmation of the fact that alkaline conditions are prerequisite for the crystallization of laumontite and a few other zeolites may be found also in literature. M. N. Shkabara thinks that laumontite is formed in the Caucasian deposits from hydrothermal solutions with pH = 8 to 11, at a temperature not higher than $150°$. In the Crimea and Karaganda he was able to observe a long sequence in successive separation of zeolites, whereby laumontite was the last to crystallize. The occurrence of such a variety in the composition of zeolites in terms of time and order of crystallization is attributable to the changing composition of hydrothermal waters. These, according to D. S. Korzhinskiy [9], are alkaline at the last stage of hydrothermal activity (even after the crystallization of granitoid masses), while at the initial stages they must be more acidic. But, as a whole, zeolites are characteristic of basic and neutral magmatic rocks.

Table 3

Dehydration of Laumontite

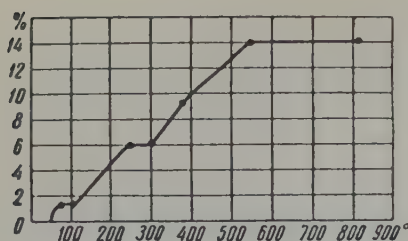| Temperature range, C^0	Loss in weight, %
40—80	1.5
100—240	4.5
300—380	3.0
380—570	5.0

The above investigations justify the belief that laumontite of sedimentary origin (from Cretaceous sandstones) is indistinguishable from laumontite of hydrothermal origin.

A review of published data reveals that several types of zeolite are to be encountered in sedimentary rocks and that they are accompanied by a fairly motley complex of authigenic materials. Zeolites are associated both with chemical precipitates (limestone, chalk, phosphorite, siliceous, ferruginous formations, bauxite) and with terrigenous rocks ranging from very thin argillaceous formations, sandstone, to molasse. Finally, a variety of rocks (zeolitites), which are almost entirely made up of zeolites, may also be encountreed. Zeolites may be both of salt- and freshwater origin. They may also form in dry-land conditions: in soils, erosion pavement, and in coal.

N. M. Strakhov [13] fells that owing to the decomposition of organic matter, silty water is highly enriched by chemically active CO_2 which dissolves the surface of the fragmented grains. This results in supersaturation of the water with various components and touches off the separation of a number of authigenic minerals including zeolites, chlorites, and

Synthesis of certain types of zeolite in alkaline conditions is also reported in a number of experimental studies.

The availability of the starting material for the formation of zeolites in the ooze of reservoirs is a fairly frequent phenomenon. Yet, it is common that zeolites do not always crystallize thereby. It may be assumed that they are very sensitive to the formative medium, the details of which are unclear (concentration of the components in solution, chemical activity, the amounts of organic matter, carbonic acid, oxygen, the concentration of hydrogen ions, and so on).

This may be observed with particular clarity by the occurrence of laumontite in the section of Chay-Tumus deposits, where it is usually present in the middle, greater part, of the sandstone series or beds. In lower and upper parts of these deposits, which are relatively thin (10 to 50 m) and were formed in transition condition from the medium involving the sedimentation of

Table 4

Results of X-Ray Diffraction Analysis of Laumontite

Sample 1097 Chay-Tumus		Sample from Tuva		Laumontite from the American collection (X-RDC)		Index No.	Sample 1097 Chay-Tumus		Sample from Tuva		Laumontite from the American collection (X-RDC)	
I	$(d/n)_\alpha$	I	$(d/n)_\alpha$	I	$(d/n)_\alpha$		I	$(d/n)_\alpha$	I	$(d/n)_\alpha$	I	$(d/n)_\alpha$
2	(10.6)	—	—	—	—	27	8	2.439	6	2.44	6	2.43
—	—	—	—	10	(10.0)	28	2	2.364	3	2.36	4	2.36
10	9.45	—	—	10	9.0	29	2	2.266	3	2.28	2	2.26
2	(7.53)	—	—	6	(7.2)	30	3	2.214	2	2.22	—	—
9	6.82	—	—	6	6.6	31	8	2.147	5	2.16	6	2.17
3	6.22	—	—	—	—	32	2	2.087	3	2.09	2	2.08
1	5.58	—	—	—	—	33	1	2.049	1	2.01	—	—
4	5.03	2	4.68	2	5.0	34	3	1.990	2	1.99	2	1.99
5	(4.41)	2	4.50	4	4.6	35	6	1.957	4	1.959	4	1.95
—	—	1	4.26	7	4.29	36	3	1.873	3	1.873	4	1.87
10	4.16	8	4.16	—	—	37	—	—	3	1.911	—	—
—	—	1	(4.03)	8	4.07	38	4	1.850	2	1.851	—	—
4	3.89	2	(3.88)	—	—	39	1	1.825	3	1.820	—	—
—	—	1	3.76	—	—	40	2	1.796	2	(1.796)	—	—
5	3.66	5	(3.67	—	—	41	4	1.755	2	1.759	2	1.76
10	3.52	7	3.52	8	3.56	42	—	—	2	1.729	—	—
5	3.38	10	3.35	6	3.40	43	2	1.702	3	1.704	2	1.70
3	3.27	3	3.28	6	3.24	44	1	1.683	3	1.674	—	—
4	3.20	5	3.20	4	3.13	45	—	—	3	1.632	—	—
—	—	1	3.10	—	—	46	7	1.620	6	1.623	6	1.62
7	3.03	9	3.03	4	3.02	47	—	—	3	1.603	—	—
6	2.870	4	2.88	6	2.85	48	3	1.591	1	1.592	2	1.513
5	2.793	3	2.80	4	2.79	49	3	1.560	2	1.565	—	—
1	2.708	2	(2.70)	—	—	50	6p	1.520	4	1.542	4	1.524
									5	1.524		
5	2.572	4	2.58	4	2.58	51	2	1.492	2	1.487	2	1.492
4	2.518	3	2.52	—	—	52	5	1.435	5	1.438	—	—

...l-bearing series to the medium of sandstone [ac]cumulation, laumontite is absent. It is re[du]ced by hydromica, a mineral characterized [by] a broader range of formative conditions.

In the described Cretaceous sandstones of [Le]na basin, the development of laumontite [fol]lows the formation of chlorite. Hydromica-[ce]ous material emerges as a result of parallel [pr]ocesses in other sections, while calcite forms [en]largely developed concretions. The calcite [gr]ains observable within the crystals of lau-[m]ontite may indicate an earlier separation of a portion of calcite.

[The] Sandstones with laumontite in their cement [con]tain many fragments of carbonized wood, [co]al, and coaly detritus, and, as previously [m]entioned, an abundance of large calcitic con-[cr]etions. Formation of the latter must be at[tri]buted to the alkaline medium. However, the [sc]antiness of pyrite and absence of magnesium [ca]rbonate in the rocks justify the belief that the [m]edium was considerably desalinized. In the

ooze, on the other hand, where zeolite and other authigenic minerals developed during the stage of diagenesis, the medium exhibited reducing conditions. Chlorite was first to form, then calcite, zeolite or hydromica which fill in the hollows of the pores. Crystallization of calcite occurred with greater intensity around certain centers (sandy concertions). In the carboniferous sediments accumulated in the conditions of swampy lands abounding with organic matter, in the ooze, the conditions were even more conductive to reduction, the pH values being low. This contributed to the formation of kaolinite, siderite, and pyrite (in insignificant quantities), whereas development of calcite proceeded on a smaller scale.

In the Chay-Tumus deposits of Lena basin, sedimentation of the Olenek series occurred unevenly. Sometimes in a large, shallow and desalined basin fed by rivers carrying detrital rock material (in deltas, and bed loads) where fragmented rock material, vegetable debris, and detritus were deposited contributing to the

formation of thick sand deposits. Sometimes in
the conditions of marshy lands where layers of
fine-grained sandstone, siltstone, argillite,
and coal were formed. These conditions alter-
nated repeatedly as reflected in the rhythmic
structure characterizing the section of the
coal-bearing basin where sandstone series or
strata are interbedded with carboniferous for-
mations.

The rhythmically alternating conditions of
sediment formation are followed by similarly
alternating changes in the composition of ter-
rigenous grains. The carboniferous series
contain a comparatively high proportion of
quartz, garnet, ilmenite, and an insignificant
amount of epidote. The non-carboniferous
formations show a larger quantity of feldspars
and a lot of epidote. Just as rhythmic, is the
variation from stratum to stratum in the com-
position of authigenic minerals. Laumontite,
authigenic hydromica, chlorite, calcite,
sphene are to be found in the sandstone forma-
tions. The coal-bearing series reveal kaolin-
ite, siderite, a lesser proportion of chlorite and
calcite, as well as other titaniferrous minerals
(such as brookite, anatase, and rutile).

The regularity specific for the area of Chay-
Tumus deposits has its continuation in the un-
derlying formations developed in the left-bank
region of the Olenek channel. Investigation of
each coal-bearing and sandstone bed of the
Lukumay series, as well as of the underlying
carboniferrous Ogoner-Yuryakh suite (from
P. I. Glushinskiy's samples) confirms the dis-
closed regularity. The same is applicable to
the composition of the strata located still deeper,
the supra-Bulun, supra-Kyusyur, and Kigilyakh
series, and the upper sand beds of the Valangin-
ian. The same regularity apparently is to be
registered also in the Bulun district, where the
Olenek and Lena series are developed and in
which coal-bearing starat alternate with non-
carboniferous formations. In 1955, B. I. Test
conducted here only preliminary lithologic in-
vestigations. A review of the relatively limited
material produced by this author shows that
zeolites are present in four non-carboniferous
suites (Kigilyak, supra-Kyusyur, supra-Bulun,
and Lukumay), while the coal-bearing strata
which separate them (Kyusyur, Bulun, Ogoner-
Yuryakh) revealed no zeolite.

Northwest of Chay-Tumus, in the region of
Olenek River, the rhythmic structure becomes
less pronounced in terms of authigenic zeolites.
Farther to the north-northwest (in the Anabar-
Khatanga and Nordvik districts) in the north-
ernmost parts of Lena basin, as well as in the
Cretaceous deposits in the lower reaches of
the Yenisey River, no authigenic zeolites were
to be found at all. This is due to the somewhat
different conditions involving the formation of
the inter-carboniferous deposits.

In the more southerly regions (Sangary
settlement) laumontite is to be found in the thick
sandstone deposits of the Sangaryan series.
These contain coal-bearing strata represented
mostly by siltstone, argillite, and coal without
laumontite. These coal-bearing strata may be
considered analogues of the carboniferrous
formations identified in the north of the basin,
where laumontite disappears in the coal-bearing
suites and beds. Laumontite was also dis-
closed southeast of Sangary along the Gradyga
River.

The available data indicate that over the
larger part of Lena coal-bearing basin the oc-
currence of laumontite in the sedimentary for-
mations of enormous thickness (2500-3000 m)
is associated with the non-carboniferous, pre-
dominantly sandstone, beds and strata. These
formations constitute the lower parts of major
cycles. In the coal-bearing beds and suites
serving as the upper part of the cycles no lau-
montite is to be registered. Over the entire
area of the basin, laumontite is known to be
present in deposits extending for a distance of
more than 1000 km.

According to the data produced by N. V.
Rengarten and T. A Ishina, laumontite was
revealed in deposits which by age correspond
to the Sangaryan series in the rocks of the
south Yakutiya coal-bearing basin [12].

The widespread occurrence of laumontite
in the Lower Cretaceous deposits of western
Yakutiya is attributable to the uniform cir-
cumstances of sedimentation over a vast ter-
ritory, where the formation of calcitic zeolite
took place in silt deposits of a desalinized
basin, as well as in alluvial (?) deposits, during
the diagenetic stage. In periodic swampy-
plain conditions, the circumstances of sedi-
mentation were unfavorable for laumontite for-
mation.

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MINOR INTRUSIONS IN THE LENINOGORSK REGION[1]

by

M. A. Osipov

Considerable attention is being devoted nowadays to the formation of dikes and other minor intrusions of different origin, the place they occupy in the magmatic process, and their role in mineralization. There are several classification systems for minor intrusive bodies. Dikes are usually classed in these systems into major groups in accordance with their genetic and age characteristics. Complexes of minor intrusions formed in the final stages of tectonic-magmatic cycles accompanying the development of mobile belts are included by some authors in a special group. It is believed that certain types of ore manifestation are paragenetically related to these complexes. F. K. Shipulin [9], in particular, has shown such regularities for some types of mineralization as exemplified in certain regions of the Far East. The role of minor intrusions in mineralization is now being recognized by an ever growing number of authors.

In view of the existence of such opinions, the hitherto neglected areas deserve to be made the subject of closer examination. For example, in Rudnyy Altay, where dike belts are known to extend for a considerable length, the problem of their origin and relationship to mineralization was studied quite insufficiently.

Although only few authors have devoted their attention to the dikes in Rudnyy Altay, a close spatial relationship between polymetallic mineralization and dikes with basic composition was noted by many investigators. As a matter of fact, as much as a century ago these dikes in the Zyryanovskiy mine were considered as "almost the sole" guiding indication for prospecting and exploratory operations. In 1957, an article was published by L. G. Nikitina dedicated to dike formations in the Zyryanovskiy region. A spatial connection between dikes with basic and neutral composition and polymetallic mineralization was also noted therein [5].

In 1958, F. K. Shipulin published a paper [10] providing the pattern of development of intrusive

magmatism based on the example of the Zyryanovskiy area. He identifies the complex of minor intrusions with basic and neutral composition, and points out that they are the youngest of all the intrusive formations in this region. Polymetallic mineralization is spatially and paragenetically related to the dikes.

A far greater number of studies is confined to minor intrusive bodies of acidic composition which are widespread in the Rudnyy Altay area (plagiogranite - porphyries, quartz porphyries, felsite porphyries, and so on). This is due to the fact that many investigators were apt to relate polymetallic mineralization precisely to porphyritic intrusions. Noteworthy in this respect is the article written by V. I. Chernov [6]. The author provides a detailed description of the porphyritic intrusions in the northeastern part of Rudnyy Altay. Among them he distinguishes the small regional intrusions assigning them to the Middle Devonian subvolcanic facies.

First to apply the term minor intrusions to the Leninogorsk region were K. G. Bogdanov and Z. V. Sidorenko. This general designation they have applied to a number of genetically different minor intrusive bodies located within a small section of the region which includes the area covered by the Leninogorsk ore field proper. The minor intrusions specified by these authors cannot be considered as such in terms of Yu. A. Bilibin's definition.

No spatial investigation of dike formations has ever been undertaken in this region.

The closest approach to this subject on a scale embracing the entire region was made by N. N. Kurek, even though he has dealt with this matter also only in an indirect manner. On the basis of certain indications, N. N. Kurek has expressed an opinion that the dikes with basic composition were formed over a long period of time as a result of repetitious injections of magma.

G. N. Shcherba [11] assigns all dikes, including those with basic composition which are

---

[1]Malyye intruzii rayona g. Leninogorska.

eloped in large numbers within the confines
he Leninogorsk ore field, to the dike forma-
of solid masses (Sinyushinskiy and Ivanov-
) of granitoids. However, in the same paper
states that many of the Leninogorsk ore-
d dikes constitute the "roots of Devonian out-
rings". Thus, doubtlessly, they represent
itively different genetic formations related
he deep-seated magmatic centers rather
to concrete intrusive masses.

V. I. Chernov and V. N. Gavrilova [7] desig-
e the various dike formations in Rudnyy
ay, including those in the Leninogorsk region,
'rocks of the vein phase" referring to the
ividual intrusive granitoid complexes. More-
r, within the scope of the vein phase for
h complex they identify "veins of the first
ge", mainly leucocratic differentiates of
cific intrusives (aplites, pegmatites, etc.),
"veins of the second stage" embracing all
remaining numerous dikes, regardless of
ir composition.

The investigators mentioned above have de-
oped schemes for relative ages in the se-
nce of intrusions of dikes with varying com-
itions. As a rule, these schemes differ one
m another. The only common feature for
st of them is, perhaps, the statement that the
rusion of basic dikes begins with the gabbroids
is then followed by alternate intrusions of
es with basic and acidic composition [11].
each of the proposed schemes the process is
divided into stages of intrusion for dikes of
ne specific composition, for example, "dia-
ic stage", "felsitic stage", each following
other and separated from one another by
re or less considerable periods of time. G.
Shcherba [11], for instance, provides the
lowing sequence pattern of dike formation
ging from the ancient to the younger dikes
the large Sinyushinskiy granitoid massif:
medium-grained granites and granitoids; 2)
broic diorites; 3) diabases and diabasic por-
rites I: 4) granodioritic porphyries; 5) gran-
porphyries and microgranite porphyries; 6)
phyrites and lamprophyres, diabasic por-
rites II; 7) aplites; 8) quartz porphyries and
phyries; 9) felsite porphyries. Noteworthy
re is the fact that the aplite dikes in this
eme are separated from the parent granitoids
intrusions of other dikes, including three
ges of intrusion by dikes of basic composition.

A slightly different scheme is provided by
I. Chernov and V. N. Gavrilova [7] for the
me Sinyushinskiy massif. According to their
ta the oldest are the aplites and leucocratic
crogranites. Veins of the second stage are
mposed of felsitic granite porphyries, diorite
rphyries, and gabbroic diabases. Their for-
ation proceeded from acidic to basic.

The above examples show how different are
e views of various investigators on the process
dike formation in the Leninogorsk region.

A special study of dike and similar formations
was carried out by us in the Leninogorsk region.
Some of the ensuing data are reviewed in this
article.

GENERAL FEATURES OF THE REGION'S GEOLOGIC STRUCTURE

In the geology of the Leninogorsk region, it
is important to emphasize certain peculiarities
in the spatial distribution of the dike formations
under review. This region is located in the
central part of Rudnyy Altay. It is made up
mainly by volcanic-sedimentary rocks of the
Middle and Upper Devonian, which unconform-
ably overlie Ordovician (?) metamorphic schists.
The Paleozoic deposits are covered by thick
masses of granitoids of different age.

The area under review coincides with the
core of the Sinyushinskiy anticlinorium, which
has a northwesterly strike and is intersected by
two branches of the, so-called, "Northwestern
crumpled zone", the major tectonic line de-
limiting the Rudnyy Altay structure on the north-
east. Both limbs have also a northwesterly
trend (Figure 1). One of them passes directly
through the city of Leninogorsk extending to the
northwest and southeast of it and extending be-
yond the bounds of the region. Located within
this limb is the Leninogorsk ore field with the
exposed Ridderskiy group of polymetallic de-
posits. The second limb passes some 20 to 25
km east of Leninogorsk (Butachikhinskaya zone).
In the northwest, beyond the limits of the re-
viewed region both limbs merge together.

Both limbs are from 1-2 to 15 km wide and
represent linearly extended zones of intensive
rock fracture and crumpling. They cut through
all the volcanic-sedimentary and intrusive rocks
in the region, by-passing only the central por-
tions of the largest granitoid masses. They are
of ancient origin and bear signs of multiple
more recent developments. The latter observa-
tion is confirmed by the fact that they cut across
the dikes which are abundantly developed through-
out the entire extent of these zones.

A coincidence of dikes with basic and acidic
composition with zones of fracture was noted
by G. F. Yakovlev [12].

GENERAL INFORMATION ON THE DIKES OF THE REGION

Three genetically distinct groups of dikes may
be identified in this region.

The first group - derivatives solid masses
of intrusive rocks: a) of granitoid intrusions
of varying ages, included herein are the
fine-grained granites, aplites, and pegmatites;
b) gabbroids belonging to the, so-called,
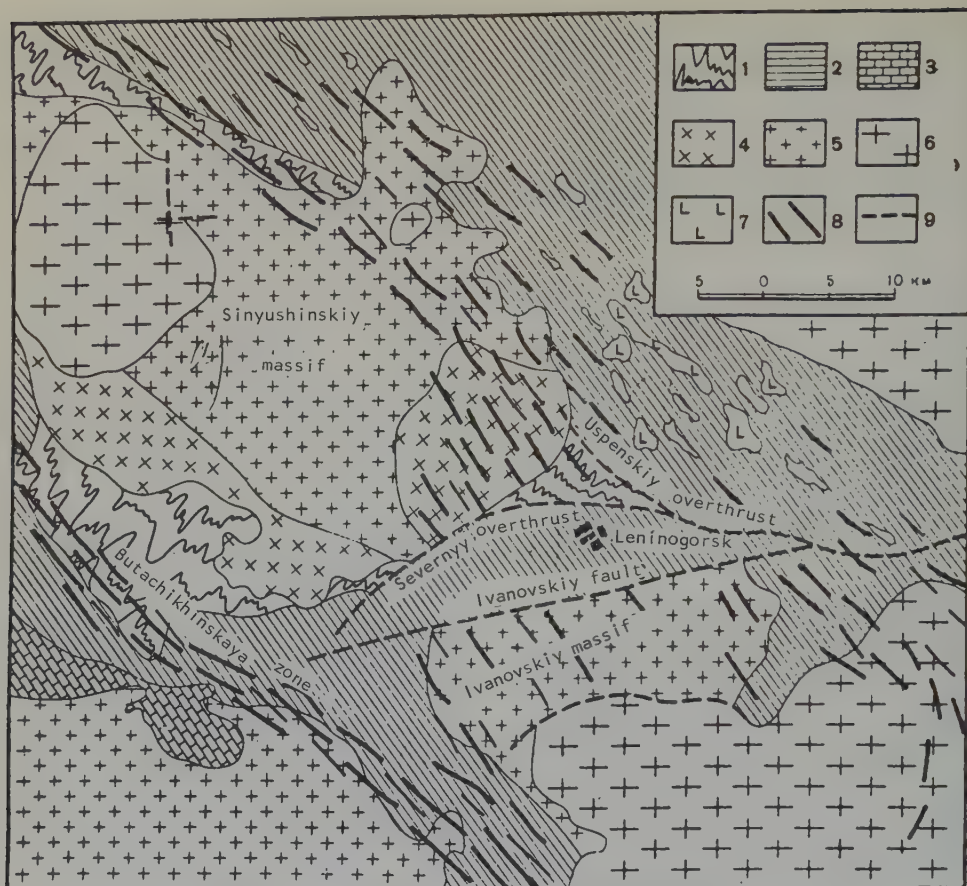
FIGURE 1. Schematic map of the Leninogorsk region geologic structure

1 - Ordovician (?) metamorphic schists; 2 - Devonian volcanic-sedimentary deposits; 3 - essentially Carboniferous sedimentary deposits; 4 - pre-Middle Devonian granitoids, 5 - granitoids of the Zmeinogorsk complex (Upper Cambrian to Permian); 6 - granitoids of the Kalbinskiy complex (Permian); 7 - gabbroic disbases; 8 - minor intrusions (dikes); 9 - lines of faulting.

pre-Zmeinogorsk intrusive complex assignable to the second half of the Carboniferous. The number of these latter dikes is small. Both aschistic (labradorite porphyrites) as well as diaschistic rocks (pegmatites, plagioclases) are recorded among them.

Dikes of the first group are to be found within the parent formations, or nearby. The geochemical similarity between them and the rocks of parent intrusions is observable in all cases.

The second group - roots of extrusions of basic or acidic composition. The recognition of this group results from the very fact of the existence of extrusions. Dikes of this group are, apparently, scarce and insufficiently studied.

The third group - dikes of basic or acidic

composition independent from these or other masses of igneous rocks. These dikes were noted both in the volcanic-sedimentary strata (Butachikhinskaya zone, the eastern and north-eastern fringes of Sinyushinskiy massif) and in the granitoid formations (Sinyushinskiy, Ivanovskiy, northern part of Serzhikhinskiy massifs, and others). They coincide strictly with the described zones of fracture and are practically absent outside of them.

Together with the fracture zones, these dikes extend far beyond the limits of the granitoid development area. Without showing any change in composition, they cut through the granitoid masses of different age.[2] Thus, the mass of

[2]The age of the granitoid formations in the Leninogorsk region is estimated according to N. N. Kurek's and V. P. Nekhoroshev's determinations [3, 4].

es with basic and acidic composition occurs
he southeastern part of Sinyushinskiy massif
consisting of granitoids dating to the pre-
dle Devonian. This fracture zone, abound-
with dikes, extends without any substantial
nges also through the more leucocratic gran-
ds in the northeastern part of the same mas-
. Its age is established as Upper Carbonif-
us - Lower Permian (Zemigorsk intrusive
plex). Southeast of Sinyushinskiy massif,
same zone and similar dikes are observable
he Ivanovskiy massif (Zmeigorsk complex).

Farther east of the Ivanovskiy massif be-
en the Pravaya and Levaya Gromotukha
ers, numerous dikes with basic and rarely
dic composition occur in the granitoids of
binskiy complex (Permian).

The Butachikhinskaya zone cuts off the north-
tern projection of Serzhikhinskiy and the
stern part of Ivanovskiy massifs of the Zmei-
sk complex.

Almost all dikes have a northwesterly strike
rely, northeasterly) and steep angles of dip.
hin the fracture zones they occur mostly in
ups of up to several score of parallel dikes.
ltiple intrusions of dikes into the same frac-
es and the formation of joints and series are
be observed. Individual dikes may extend
r a distance of several hundred meters.
eir thickness ranges from a few centimeters
tens of meters.

The character and sequence of dike intrus-
s is illustrated in the descriptions of out-
ps which will be found below.

THE TIKHAYA RIVER OUTCROP

The building-stone quarry located at the
right bank of Tikhaya River, approximately 1 km
upstream from Sharavki village is shown in
Figure 2. Exposed here in the vertical wall of
the quarry, 40 m long and 6 m high, is a series
of dikes with basic and acidic composition and a
northwesterly strike. The dikes are located in
the granitoids of Sinyushinskiy massif, ranging
from 0.1 to 7 m in thickness and showing a dip
of 60 to 90°.

Exposed at the outcrop are dikes of uralitized
fine-grained gabbros, diabasic porphyrite, al-
bitized plagiogranite porphyries, spherolitic
and felsitic porphyries. The enclosing granit-
oids are split by the dikes into plates and wedges
of different thickness. Dikes of basic and acidic
rocks have well outlined quenching zones. A
careful study of the dike correlation in this out-
crop made it possible to identify a number of in-
trusion stages (from the oldest to the more re-
cent ones).

URALITIZED GABBRO (GABBRO-DIABASES)
AND DIABASIC PORPHYRITES
(FIRST STAGE OF INTRUSION)

The dike from which sample 0-42^a was taken
(right-hand section of Figure 2) is made up of
gabbro. The dike has a heterogeneous struc-
ture, the gabbroid proper composes only its
central part. Toward the contacts, the gab-
broids gradually give way to diabasic porphyrite.
Plagioclase phenocrysts occur in the rock and
the ground mass has a diabase-like texture.
Along the center the gabbro dike is sectioned by
a parallel dike of spherolitic porphyries which
change into felsite near the contacts.
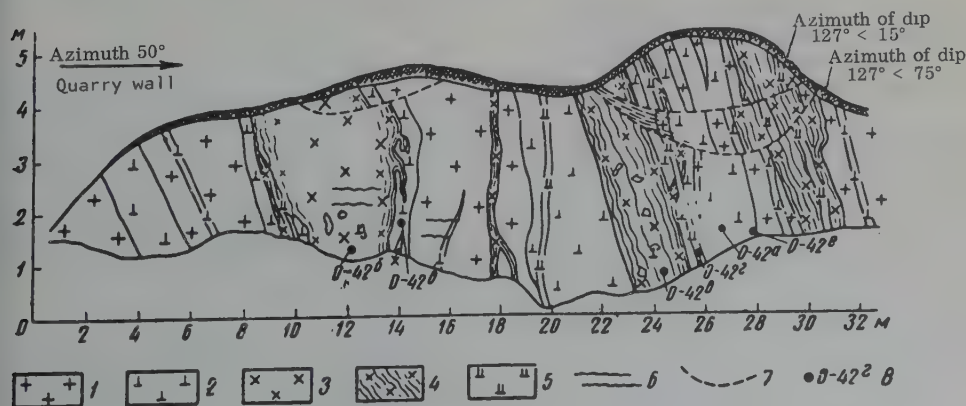

FIGURE 2. Sketch of the quarry wall at Tikhaya River

1 - plagiogranite, adamellite; 2 - gabbro and diabasic porphyrites (dikes of the first
stage); 3 - plagiogranite porphyries (second-stage dikes); 4 - spherolitic and felsitic
porphyrie, felsite (second-stage dikes); 5 - diabasic porphyrite (third-stage dikes);
6 - quartz veinlets; 7 - faultings; 8 - locations and numbers of samples.

The rocks which form the gabbro dike are dark green in color. They have been considerably altered, manifested in a complete replacement of most primary minerals. Consequently, microscopic examination reveals mainly fibrous amphibole, albite, and chlorite. Present in smaller quantities are epidote, clinozoisite, magnetite, pyrite, leucoxene, sericite. A precise count of minerals turned out to be impossible owing to the complicated interrelationship of minerals due to metasomatic processes.

Fibrous amphiboles are unevenly distributed in isolated "grains". The orientation of mineral fibers within such "grains" is always parallel. The clustered arrangement of amphibole grains suggests the possible replacement of pyroxene by it. The pyroxene is present in unaltered rocks. This supposition is corroborated by numerous observations in other less altered gabbroid dikes, where alongside with totally replaced pyroxenes fresh augite was found to be present.

Closer to the contacts, where the rocks assume a porphyritic texture, the amphibole fibers are more randomly oriented and do not form any clusters. The plagioclase contained in the phenocrysts and the ground mass is albite. In the less altered first-stage gabbroid dikes in other outcrops the preserved plagioclase grains are composed of andesine-labradorite. The size of phenocrysts is up to 2 x 3 mm, up to 20% of the rock. Their shape, broad, unclearly delineated plates. Observable in the middle sections of the largest phenocrysts are deposits of minerals belonging to the epidote group.

Characteristic of the rocks is highly ferruginous epidote of a pistachio-yellow color. This type of epidote, in contradistinction to the colorless type which replaces the feldspars and is evenly developed in the rocks, is a coarser grained variety. It forms isolated deposits (lenses) of spherical shape up to 3 mm in size, or, less frequently, fine veinlets.

Diabasic porphyrite. It was stated above that diabasic porphyrites are related to gabbro by mutual transitions, but they also form independent dikes. In the outcrop under review the diabasic porphyrite composes a dike from which sample 0. 42^d was taken (middle section of Figure 2). The dike is vertical and about 1 m thick. On the northeastern side, it contacts the granitoid mass and has a zone of quenching. A parallel dike of plagiogranite porphyry, which changes into felsitic porphyry towards the contacts, abuts against it from the southwest.

The contact line between the porphyrites and plagiogranite porphyry is winding, tortuous, and without a quenching zone on the side of the porphyrite. In its lower section exposed in the outcrop the porphyrite dike is cut by the apophysis of a dike made up of plagiogranite porphyry

which changes into felsite porphyry. The porphyrite dike is formed by the same minerals as the previously described dike of gabbroid porphyrite. Primary minerals are also almost absent from its composition. They are replaced by fibrous amphiboles, chlorite-epidote, albite, leucoxene, and serecite. Albite is the mineral forming the phenocrysts. Apart from colorless epidote which replaces plagioclase, lenses of pystachio-yellow epidote are observable in the rocks.

As may be seen from the description, the first stage of dike-rock injection is represented by gabbroids (gabbroic diabase) which is related by gradual transitions to diabasic porphyrite masses and independent dikes of diabasic porphyrite.

PLAGIOGRANITE PORPHYRIES, SPHEROLITIC AND FELSITIC PORPHYRIES (SECOND STAGE OF INJECTION)

The second intrusion stage in this outcrop is represented by dikes of plagiogranite porphyry related by gradual transitions to spherolitic and felsitic porphyry and independent dikes of spherolitic and felsitic porphyry. Four such dikes were noted, two of them were referred to above. They intersect with the first-stage dikes of basic composition.

One of them, the largest, is exposed in the southwestern half of the outcrop. It has a vertical dip and shows an average thickness of 5 m. On the southwestern side it abuts on the previously described porphyrite dike (first stage) which it intersects, while on the northeastern side it comes into contact with another porphyrite dike. The acidic dike contains xenoliths of porphyrite. Along the contacts on both sides it has wide quenching zones.

This dike has a heterogeneous structure and is made up in its central part by plagiogranite porphyries which gradually change towards the contacts into less crystallized varieties: spherolitic, and then felsitic porphyries. Phenocrysts are absent in the quenching zones and the rocks assume a felsitic structure. Fluidal texture becomes manifest running parallel to the bends of the contacts. The thin apophysis of the dike is also composed of felsite.

The plagiogranite porphyries are mainly composed of quartz - about 60%, and albite - about 40%. They constitute the phenocrysts (up to 30 or 40%) and the greater part of the rock groundmass. The ground-mass texture is microgranitic, less frequently granular.

Small accumulations of fine laminae of biotite, represented by two varieties, green and brown, are to be registered. The form of biotite deposit: wide laminae in the green variety, sharply

ongated in the brown type. These usually de-
velop around deposits of green biotite. Together
with ferric hydroxides, brown biotite penetrates
into the minutest fissures. Present in the rock
also are fine grains of zircon, frequently with
low birefringence, and apatite. Of the secondary
minerals epidote, sphene-leucoxene, chlorite,
sericite are common. Characteristic is epidote
which forms veinlets and deposits of round
shape with a diameter of 3 to 5 mm, and radial-
fibrous texture. The central sections of these
deposits display pleochroism in showing tints
ranging from light brown, or colorless, to
pinkish-brown.

Phenocrysts of plagioclase (albite) and quartz,
numerous in the middle part of the dike, dis-
appear towards the contacts. However, in the
well preserved and thicker dikes of this series
in other outcrops, where their middle plagio-
granite porphyritic section is more pronounced,
relics of the basic oligoclase, acid andesine
(Nos. 31-37) and potassic feldspar, are present.

Quartz in the phenocrysts usually has a bi-
pyramidal shape and is often fused. After
cleavage of rocks which form these central most
crystallized portions of dikes, these diapyramids
project from the cleat face. But whenever the
denser felsitic parts of the very same dikes are
cleaved, the phenocrysts are sheared off at the
surfaces of the fracture.

The other second-stage dike with acid compo-
sition, which was also mentioned earlier (it
intersects the gabbroid dike), is thinner (3 m)
and its dip angle in the northwesterly direction
is 70°. This dike is made up of spherolitic and
felsitic porphyries and its quench zones are re-
presented by fluidal felsites. A heterogeneous
zonal structure is also to be registered here,
although the degree of crystallization of the
central part of this dike is smaller than in the
preceding one, because of its lesser thickness.
The mineralogic composition of the spherolite-
felsite porphyry dike is similar to that of the
acidic dike in its section composed of struc-
turally similar rocks.

An apophysis branches off from this dike.
It cuts through the first-stage uralitized gab-
broid dike, and is no more than 0.5 m thick.
It is composed of fluidal felsite. This apophysis,
in turn, is intersected by a dike of porphyrite
belonging to the following, or third stage.

DIABASIC PORPHYRITES
(THIRD STAGE OF INJECTION)

The third injection stage of dikes is repre-
sented in the outcrop by thin bodies of diabasic
porphyrite (no more than 0.5 m thick). The
porphyrites of this stage intersect the dikes of
plagiogranite porphyry and felsite. Three such
intersections are to be registered: two, already

mentioned above, and one located at the north-
eastern extremity of the exposure. Here the
dike of spherolitic porphyry and felsites is cut
through along its middle by a parallel dike of
diabasic porphyrite about 0.5 m thick.

The porphyrite is of the gray-green variety.
Microscopic examination reveals a small quan-
tity of phenocrysts (not exceeding 2 mm in
length) of albite, hornblende (up to 1.5 mm in
length), and a fine-grained groundmass con-
sisting of plagioclase, and mainly secondary
alteration products (carbonate, epidote, chlorite,
quartz, fibrous amphibole, magnetite, pyrite,
leucoxene, sericite). These are younger rocks
than the first-stage porphyrites, and we were,
therefore, able to determine certain constants
for these minerals, in particular, for horn-
blende. The color of this mineral is brownish-
green; birefringence in phenocrysts is up to
0.016, in the groundmass up to 0.026; c:γ is up
to 17° in the phenocrysts, and up to 19-22° in
the ground mass; 2V = about 75 to 84°.

The hornblende phenocrysts are unevenly
distributed in the rocks. In places their number
is considerable, while the proportion of the
plagioclase phenocrysts is smaller, and in these
places the rocks assume an aspect similar to
that of lamprophyres. The rocks also contain
pistachio-yellow epidote which forms separate
deposits and fine veinlets. Secondary fibrous
amphibole is developed in the groundmass and
replaces hornblende.

The other porphyrite dikes of the same stage
do not contain any unreplaced hornblende in this
outcrop, but only secondary minerals. These
rocks do not differ in any respect from the dia-
basic porphyrite of the first stage.

From the description of the outcrop, it is
possible to draw the following conclusions. 1)
The injection of fikes must have occurred in
three stages. 2) The first stage is represented
by uralitized gabbro (gabbroic diabase) related
by gradual transitions to diabasic porphyrite
and to the independent dikes of diabasic por-
phyrite, whereas gabbroids (or the evenly-
grained varieties, in general) form only the
central parts of the thickest dikes of this stage.
3) The second stage is characterized by the
presence of plagiogranite porphyries related by
gradual transitions to spherolitic and felsitic
porphyries and felsites, and to the independent
dikes of spherolitic and felsitic porphyries and
felsites. The degree of crystallization depends
on the thickness of the dikes. 4) The third
stage is represented by dikes of diabasic por-
phyrite. By their structural and mineralogic
features, the rocks of this stage resemble the
porphyrite of the first stage. The only differ-
ence consists in a slightly greater freshness of
some of the third-stage dikes, and in the pre-
sence of indications emphasizing their close
similarity to lamprophyres.

OUTCROP ALONG THE
LENINOGORSK - LIVINO ROAD

An outcrop located approximately 1.5 km northeast of the city of Leninogorsk, a few meters off the Leninogorsk-Livino highway, gives a further idea of the pattern of dike-rock intrusion in the region under survey. The rocks are exposed in a minor building-stone quarry. Just as in the preceding outcrop one may observe here a series of basic and acid rock dikes cutting across the Ordovician (?) metamorphic schists. All the dikes have a northwesterly trend (the azimuth of dip ranging from 25 to 80°), dip angles of from 10-18° to 70° and thicknesses ranging from 2-3 cm to 8 m.

The third stage of intrusion is represented in this outcrop by a branching dike of diabasic porphyrite (sample 0.40^3) and a dike of altered diabase (sample L-8). Both cut across the dikes of plagiogranite porphyry, forming up to 15-cm wide contact-metamorphic zones. The diabase dike is heterogeneous in texture: in its middle part it is made up of evenly-grained varieties of rocks with ophitic texture. These gradually give way to diabasic porphyrite toward the contacts. The rocks contain: albite, fibrous amphibole, chlorite, epidote, magnetite, pyrite, leucoxene, sericite, and carbonate. Epidote forms isolated deposits in which it often displays a pistachio-yellow color. In structural and mineralogic characteristics the rocks of these
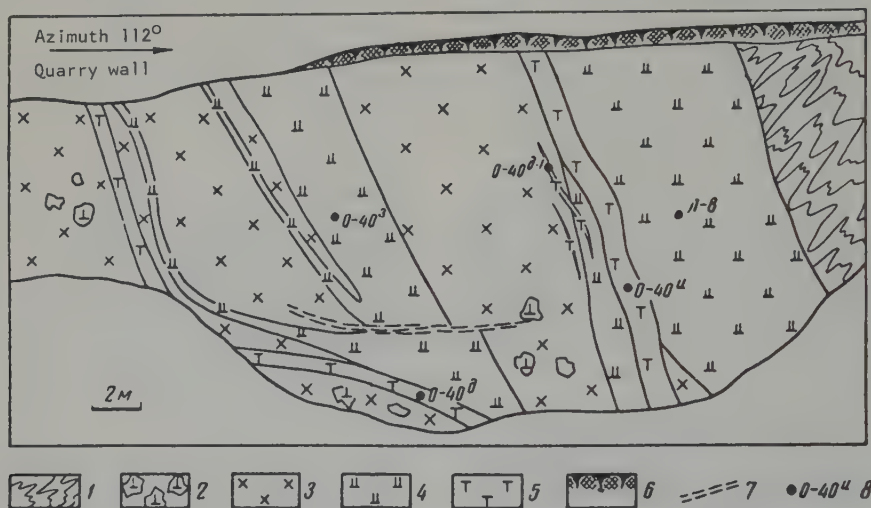
FIGURE 3. Sketch of the quarry wall at the Leninogorsk-Livino road

1 - Ordovician (?) metamorphic schists; 2 - xenoliths of porphyrite; 3 - pliogranite porphyries, spherolitic and felsitic porphyries, felsite (second-stage dikes); 4 - diabase, diabasic porphyrite (third-stage dikes); 5 - diabasic porphyrite (fourth-stage dikes); 6 - organic soil layer; 7 - zones of fracture; 8 - locations and numbers of samples.

The above sketch (Figure 3) shows the southeastern half of the outcrop exposing the dikes of plagiogranite porphyry which are gradually replaced near the contacts by spherolitic and felsitic porphyries. Acidic-rock dikes were cut in two successive stages of intrusion by dikes of basic composition. In the description of the previous outcrop it was shown that the plagiogranite porphyry and felsite are second in order of intrusion. The acidic dikes in this outcrop do not differ in any respect from those described above. They contain albitized plagioclase and quartz accompanied by green and brown acicular biotite, zircon, apatite, and an ore mineral. Characteristic are the round radial-fibrous deposits of epidote displaying dichroism in shades of red and brown. The quartz phenocrysts are fused and have a bipyramidal shape.

dikes are similar to those contained in the third-stage dikes described from the preceding outcrop.

DIABASIC PORPHYRITE
(FOURTH STAGE OF INTRUSION)

Both third-stage dikes are in turn cut by dikes of diabasic porphyrite (fourth stage). In this outcrop, the fourth stage is represented by a tortuous dike of diabasic porphyrite, from which sample 0.40^d was taken (left-hand section of Figure 3), and the diabasic porphyrite dike typified by sample 0.40^i (right-hand section in Figure 3). The former is about 0.5 m thick and has a dip angle of 10 to 70°. It displays a contact metamorphic zone at the contact which is approximately 2 cm wide.

The rocks composing this dike are dark,
greyish green. They have a porphyritic tex-
ture with an ophitic texture of the groundmass,
but the insets are small (up to 1.5 x 1 mm),
hardly discernible and comprise 10% of the
rock mass. The phenocrysts contain albite,
the groundmass: albite, fibrous amphibole,
chlorite, epidote, leucoxene, magnetite, pyrite,
sericite, occasionally fine allotriomorphic, and
at places round, deposits (lenses) of quartz.
Round deposits of pistachio-yellow epidote are
also present.

The second, fourth-stage dike (sample 0.40^i)
is about 1.5 m thick and made up of diabasic
porphyrite. Its rocks differ from the porphyrite
of the first dike of this stage only in having
somewhat larger albite insets.

Apart from these, several diabasic por-
phyrite dikes are also exposed in the outcrop,
but there are no clear-cut criteria which would
permit them to be assigned to this or that stage.
It is possible that still another injection stage
of basic-composition dikes may have taken
place here.

Thus, it is possible to make the following
conclusions on the basis of this outcrop descrip-
tion: 1) In addition to the previously described
three stages of dike injection, there must have
been still another intrusive stage represented
by diabasic porphyrite. 2) The diabasic por-
phyrite of this last stage, by its textural and
other petrographic characteristics, is similar
to the porphyrites of other, earlier, stages of
intrusion by dikes of basic composition. The
distinction consists mainly in the more finer-
grained rock texture. This corresponds to the
smaller thicknesses of the last-stage dikes and
the appearance of quartz deposits.

The above relationships are borne out by ob-
servations conducted in other outcrops.

DIKES OF MICROPORPHYRIES AND FELSITES

Such dikes form still another stage in the
group under review. However, they occur very
rarely, and this may be the reason why we have
failed to determine their relative age with
greater accuracy, having only established the
fact that they are younger than the plagio-
granite porphyry-felsite dikes of the second
stage. Their correlation with the basic dikes
of the subsequent stages is unclear. Conse-
quently, their position in the sequence of dike
intrusion is somewhat obscure.

The intersection of plagiogranite porphyry-
felsite dikes by microporphyries was noted by
us in two spots.

OUTCROP LOCATED NORTH OF THE CITY OF LANINOGORSK

The outcrop is situated 3 km north of the city
of Leninogorsk, on a small, clearly visible
rise in the topography built up by a series of
parallel plagiogranite porphyry dikes with a
northwesterly strike and apparent thicknesses
ranging from 5 to 15 m. The plagiogranite
porphyries are cut by several porphyrite dikes
and one dike of plagioclastic microporphyry
(sample 0.38^b). The microporphyry dike, which
is about 4.5 m thick, is traceable for approxi-
mately 100 m and then disappears under the
mantle. The dike is located (dip azimuth 27°,
angle 45°) at an angle to the plagiogranite por-
phyry dike which it intersects, and which has an
azimuth of dip of 65°

Superficially, the microporphyry is a light
gray, more or less uniform rock resembling
the relatively weakly crystallized (spherolitic
and felsitic) portion of the second-stage dikes
of plagiogranite porphyries. A porphyritic tex-
ture with albite and quartz insets amounting to
about 30% of the entire rock mass is observable
under microscope. The groundmass is sphero-
litic and flesitic. Apart from plagioclase and
quartz, the rock displays occasional laminae of
green, and even less frequently, brown biotite,
as well as grains of zircon.

Zircon often displays a low birefringence,
while the central parts of the largest (up to 3
mm) round epidote grains reveal a pleochroic
play in shades of brown. These minerals have
a fibrous radial texture. In mineralogic compo-
sition the rocks are similar to plagiogranite
porphyry of the second stage, structurally they
resemble the spherolitic and felsitic varieties.

VYSHEIVANOVSKIY BELOK MOUNTAIN OUTCROP

An analogous case was noted on the eastern
slope of Vysheivanovskiy Belok Mountain. Here
the granitoids of Vyshneivanovskiy massif are
cut by a dike-like body of plagiogranite por-
phyry ranging in thickness from 20 to 180 m
and displaying a complex contact outline.

In the southwestern part the plagiogranite
porphyry is cut by a porphyrite dike 8 m thick
and by a separate dike 1.5 m thick consisting
of felsitic microporphyry and trending in a north-
easterly direction.

The microporphyry is a light-gray rock of
felsitic type, similar by its structure and min-
eralogic composition to the one described above.

On the basis of the description of outcrops it
is possible to outline the following sequence
pattern of dike intrusions of the group under re-
view (see page 68).

In both the series of basic and acidic dikes, a definite regularity is to be observed (from the oldest to the more youngest formations).
a) A reduction in the thickness of the dikes.
b) A diminuation in the size of the constituent mineral grains. The degree of crystallization is a direct function of the thickness of the dikes.

In the basic dike series we failed to distinguish even a single stage that would structurally or mineralogically differ sharply from the other stages. Each of the stages is represented by rocks constitutionally similar to porphyrite. Only in the first two, the central portions of the thickest dikes are formed by evenly-grained varieties of rocks of the same composition (gabbroids, diabases).

. Contrary to the assumptions of the previous investigators, the series of acidic dikes identified by us contains a smaller number of members. This is due to the fact that in the earlier schemes the spherolitic and felsitic varieties of plagiogranite porphyry dikes were isolated as representing independent intrusive stages. It appears that only the structural characteristics were taken for purposes of such classification. This is evident from the fact that neither of the authors, as far as we know, has supplied a detailed description of an outcrop and its location, with a direct reference to a visible intersection of two acidic dikes in the series discussed here. It seems that this is also the reason why in the previously developed schemes reflecting the sequence of dike intrusions in the Leninogorsk region, the very same rocks (for example, felsites) are shown to occupy different positions.

The rocks of the two intrusive stages for the dikes of the acid series, as identified by us, resemble each other both in terms of structural characteristics and mineralogic composition.

Thus, we have two series of dike formations parallelling each other in time and megascopically similar, within the limits of each series.

CHEMICAL DESCRIPTION OF THE DIKES

Dikes of Basic Composition

Incorporated in Table 1 are the analytical data for the dikes with basic composition. Included therein also are the results of the analyses of the basic rocks belonging to all three stages. Analytical data on basic dikes of the same group the age of which is unknown, but which are of interest from some other point of view, are given supplementally. Given, in particular, are the results of analyses of the diabase and porphyrite dikes exposed in the Leninogorsk and Bystrushinskiy mines.

Let us discuss the analytical data of the dikes whose relative age has been established by us. The compositions of these rocks are reflected in the first five columns of Table 1. All of them belong, after A. N. Zavaritskiy, to the class of feebly undersaturated SiO_2 rocks.

By contents of other elements they also are similar formations, although they reveal certain distinctions, which are manifested gradually from one stage to another. These distinctions

Pattern of Dike Intrusion Sequence

Basic dikes
First stage

Acidic dikes

Gabbroids and gabbroic diabase, related by gradual transitions to diabasic porphyrite masses, and independent dikes of diabasic porphyrite

Time

Second stage

Plagiogranite porphyry related by gradual transitions to spherolitic and felsitic porphyry and felsite. Spherolitic and felsitic porphyries, felsite

Third stage

Diabase related by gradual transitions to diabasic porphyrite masses, and independent dikes of diabasic porphyrite

Fourth stage

Diabasic porphyrite

?

Stage of microporphyrite-felsite

Table 1

Chemical Analyses of Basic Dikes

Weight percent

Composition	0-37zh	24	L-8	0-40d	0-40d-1	Ch-73	0-51	0-36g	0-36e	33 a-1
SiO_2	46.10	46.28	50.34	49.60	51.90	47.18	52.30	46.74	43.40	46.92
TiO_2	1.22	1.16	1.35	0.80	1.10	1.00	0.87	2.55	2.40	0.99
Al_2O_3	16.98	17.16	16.17	18.56	16.14	17.77	15.67	16.71	16.12	17.94
F_2O_3	2.22	3.04	3.15	2.73	4.13	4.42	3.29	4.41	1.15	3.16
FeO	6.62	6.19	6.90	6.86	5.47	4.56	5.76	6.10	7.68	7.14
MnO	0.13	0.14	0.19	Trace	0.16	0.07	0.15	Trace	0.19	0.17
MgO	9.05	7.44	7.02	7.25	6.68	8.38	7.00	6.63	6.20	8.00
CaO	12.64	11.94	6.34	4.58	4.66	11.03	7.87	7.64	8.44	11.01
Na_2O	1.82	2.23	4.51	5.01	5.00	3.17	3.55	4.52	3.83	2.11
K_2O	0.35	1.42	0.93	0.71	0.55		1.20	0.68	0.61	0.91
H_2O^+	2.67	2.00	2.65	3.05	2.75	2.04	2.62	2.61	3.68	2.02
H_2O^-	0.06	0.28	0.09	0.24	0.46	0.14	0.16	0.19	0.15	0.10
Ignition loss	0.35	None	0.40	0.46	0.29	None	None	0.95	6.47	None
P_2O_5	—	0.26	—	—	—	—	—	—	—	—
S	—	0.28	—	—	—	0.02	—	—	—	—
BaO	—	None	—	—	—	None	—	—	—	—
Total	100.21	99.82	100.04	99.85	99.89	99.78	100.44	99.73	100.32	100.47

Numerical characteristics according to A. N. Zavaritskiy

	0-37zh	24	L-8	0-40d	0-40d-1	Ch-73	0-51	0-36g	0-36e	33 a-1
a	4.5	7.2	11.59	12.1	13.2	7.3	9.6	11.3	10.2	5.9
c	9.52	8.4	5.17	5.7	4.3	8.6	5.7	5.9	6.9	9.5
b	30.74	28.6	24.22	24.3	21.9	28.1	24.2	25.4	25.7	28.3
s	55.2	55.77	59.0	57.7	60.5	55.55	60.1	57.53	57.2	56.1
f'	27.7	31.01	39.6	39.19	41.38	30.09	34.7	39.55	36.68	35.0
m'	51.37	45.6	49.57	53.7	52.03	51.7	49.1	45.9	45.56	49.5
c'	20.87	23.3	10.82	—	6.58	18.1	16.1	14.48	17.75	15.5
a'	11.01	—	—	7.15	—	—	—	—	—	—
n	90.6	70.59	88.09	92.04	93.7	100.0	81.4	91.2	91.04	76.2
t'	1.9	1.9	1.98	1.19	1.59	1.6	1.2	3.9	3.98	1.5
φ	6.4	9.4	11.39	10.15	16.3	13.9	9.0	15.59	4.14	10.5
Q	—8.0	—11.2	—10.33	—14.3	—9.6	—11.3	—4.3	—13.8	—12.9	—8.9
$\dfrac{a}{c}$	0.5	0.85	2.2	2.1	2.9	0.8	1.7	1.9	1.47	0.6

The analyses were carried out at the Chemical laboratory of the Institute of the Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry of the U.S.S.R. Academy of Sciences (IGEM).

0-37zh gabbro from the central part of the 1-m thick dike in Ordovician metamorphic schists (first stage). V. Klitina analyst.

24 " from a 15-m thick dike in granitoids of Sinyushinskiy massif (first stage). L. Krutetskaya, analyst.

L-8 diabase from the central part of an approximately 8-m thick dike in Ordovician metamorphic schists (third stage). V. Klitina, analyst.

0-40d diabasic porphyrite from a 0.5-m thick dike in Ordovician metamorphic schists (fourth stage). V. Klitina, analyst.

0-40d-1 diabasic porphyrite from a 0.4-m thick dike in Ordovician metamorphic schists (fourth stage). V. Klitina, analyst.

Ch-73 gabbro from the middle part of a dike-like body measuring 1.0 x 0.5 km in Middle Devonian deposits. M. Veprintseva, analyst.

0-51 porphyrite from the middle part of a dike-like body measuring 40 x 300 m, in Middle Devonian deposits. Ye. Kuznetsova, analyst.

0-36g diabase from a dike from Bystrushinskiy mine in Middle Devonian deposits. V. Klitina, analyst.

3-36e porphyrite form a dike in Leninogorsk mine in Middle Devonian deposits. V. Klitina, analyst. (Sample was put at our disposal by the Chief Geologist of the Leninogorsk mine, V. T. Mosolkov).

33a-1 diabasic porphyrite from a dike in granitoids of Sinyushinskiy massif. Ye. Kuznetsova, analyst.

concern mainly the contents of silica, calcium, sodium, and magnesium.

For instance, the amount of SiO_2 and Na somewhat increases in the rocks from the first stage to the following one. Moreover, the rise in Na content proceeds at a greater rate than this is the case with SiO_2. The quantities of calcium and magnesium, in contrast, diminish in the same direction. These changes correspond to the variations in mineralogic composition. It was, for instance, mentioned by us that pyroxene is present only in the first-stage gabbroid dikes. In the basic dikes of the more recent stages, even those that have been relatively weakly altered, no pyroxene is to be found. But there appears a small quantity of quartz, hence the increase in SiO_2. The growth in sodium content is related directly to the process of plagioclase albitization.

The variation in the content of divalent bases may also be connected with the decreasing role of the femic minerals (pyroxene). It is natural that it should develop in the reverse direction.

Characteristic of the rocks is the constancy in the sum total of ferrous and ferric oxides. This bespeaks the fact that the rocks of all three stages were formed by basic magma of similar composition. Deoxidation of the rocks composing the dikes from the oldest to the youngest ones may, on the other hand, be attributed to a processes of hybridization which must have proceeded more intensively in the thinner, more recent, dikes. It seems that this may be attributable to the phenomenon of magmatic differentiation in time.

In A. N. Zavaritskiy's diagram reproduced in Figure 4, the noted stage-to-stage variation of
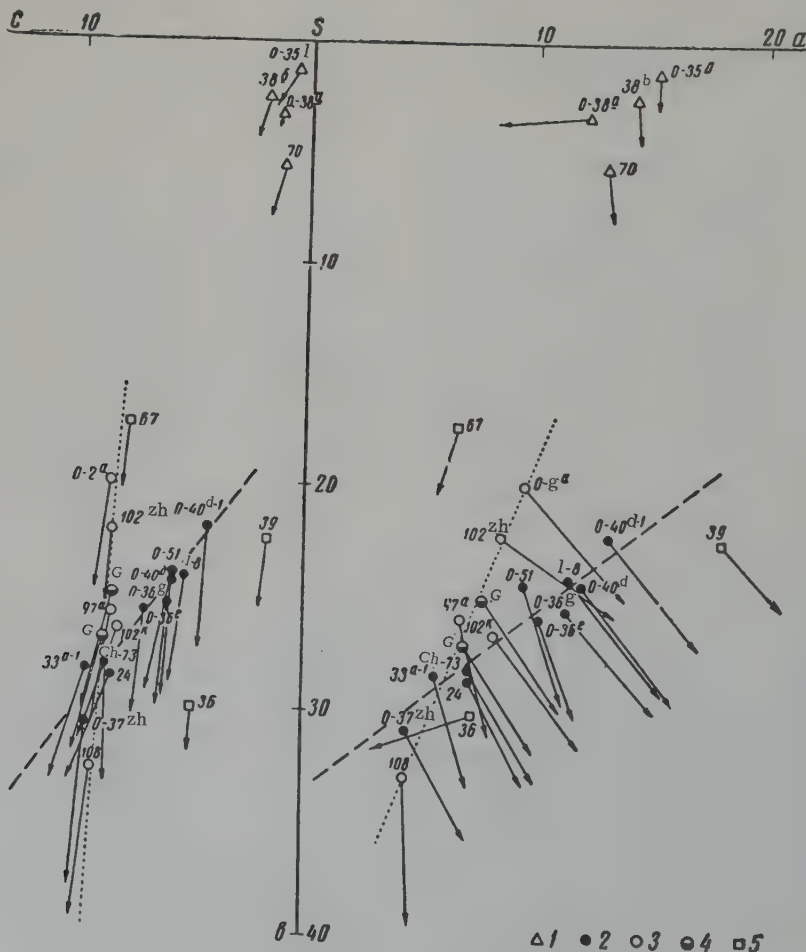

FIGURE 1. Map showing the occurrence of basalts in northern Timan

1 - Quarternary deposits, 2 - basalt, 3 - Devonian sandstone, 4 - Devonian conglomerate, 5 - Silurian limestone, 6 - pre-Silurian quartzite, 7 - first year's route, 8 - second year's route, 9 - mountains, 10 - probable outcrops of basalt.

composition may also be clearly seen. The figurative points of the basic rocks are arranged ... narrow line in succession from the first ... ge to the final one. The variation line forms ... characteristic relatively obtuse angle with axis ... This indicates the close position of the analyzed rocks to the line of alkalicized basalts and lamprophyres. The length and the inclina-tion of the vectors of the described rocks with basic composition are relatively the same.

For purposes of comparison, the figurative points for the composition of other basic rocks developed in the territory under review were also plotted on the diagram, i. e., for the gab-broids of the pre-Zmeinogorsk intrusive com-plex with their veined series (samples 97^a, 102^{zh}, 102^k, 108, 0-2^a) and for the Devonian extrusives of basic composition (samples 36, 39, 67). The results of the analyses of these rocks are given in Table 2.

The gabbroids of the pre-Zmeinogorsk com-plex and their gangue derivatives resemble each other in composition and exhibit a well-pro-nounced variation line. The figurative points,

reflecting the composition of the extrusives in the Devonian beds, on the other hand, fall in a random pattern on the field of the same diagram. The variation line for the gabbroids of the pre-Zmeinogorsk complex coincides with the gab-broid line as plotted by R. Daly (points Г on the diagram) and deviates sharply from the line of the described dikes. Such difference between the orientations of the variation lines of the pre-Zmeinogorsk gabbroids and the basic dikes in question suggests that both groups of basic rocks are genetically distinct. The intersection of the variation lines of these groups evidences the possible existence of constitutionally similar members in these groups. This justifies the origination from one and the same magmatic center. The distinctions registered for both rock groups are due to the different conditions of their formation.

Dikes of Acid Composition

The results of chemical analyses for the acid dikes of both isolated stages are to be found in Table 3. Both of them, according to A. N.

Table 2

Chemical Analyses of the Gabbroids of the pre-Zmeinogorsk Intrusive Complex, Devonian Extrusives of Basic Composition

Compo-sition	Weight per cent						Numerical characteristics according to A. N. Zavaritskiy					
	102^{zh}	0-2^a	102^k	36	39	67		102^{zh}	0-2^a	102^k	36	39	67
SiO$_2$	48.97	51.50	48.04	48.40	48.80	59.00	a	8.5	9.6	8.4	7.4	18.3	4.2
TiO$_2$	3.00	1.23	1.26	0.15	0.32	0.07	c	8.4	8.4	8.1	4.9	1.6	7.6
Al$_2$O$_3$	18.25	18.87	17.84	20.92	15.40	15.90	b	22.3	19.9	26.4	29.9	22.3	17.3
Fe$_2$O$_3$	3.15	1.52	2.05	9.88	4.45	7.94	s	60.8	62.1	57.1	57.8	57.8	70.9
FeO	8.24	6.93	7.50	3.70	5.48	3.16	f'	49.8	41.6	35.2	41.8	42.2	59.1
MnO	0.19	0.15	0.17	0.016	Trace	0.35	m'	35.0	47.3	50.7	17.2	31.4	30.0
MgO	4.40	5.31	7.68	2.92	3.98	2.90	c'	15.1	11.1	14.1	—	26.4	—
CaO	9.24	8.29	9.44	3.79	5.88	5.94	a'	—	—	—	41.6	—	8.7
Na$_2$O	3.46	3.64	2.77	2.98	7.02	1.72	n	93.3	86.8	75.0	94.1	87.6	93.1
K$_2$O	0.42	0.80	1.40	0.29	1.53	0.16	t'	4.4	1.7	1.9	0.2	0.5	—
H$_2$O+	0.57	1.47	1.86	0.43	0.34	0.48	φ	12.2	6.4	7.4	30.0	17.8	40.8
H$_2$O-	0.10	0.10	0.20	0.32	0.24	0.48	Q	−3.8	−3.4	−10.7	−24.0	−22.6	+25.8
Ignition loss	None	None	None	5.87	0.03	2.36	a	1.0	1.0	1.0	1.5	11.4	0.36
S	—	—	—	0.2	0.05	0.04	c						
CO$_2$	None	None	0.20	—	6.84	—							
Total	99.99	99.81	100.41	99.87	100.36	100.50							

102^{zh} gabbro of the pre-Zmeinogorsk complex, butte at the left bank of Ul'ba River in the fourth region of Ul'bastroy. A. Sadikov, analyst (IGEM U. S. S. R. Academy of Sciences).

0-2^a } labradorite porphyrite from the dikes which cut across the pre-Zmeinogorsk gabbroids and are in
102^k } turn intersected by the following intrusive Zmeinogorsk complex of granitoids. Analyst, A. Sadikova (IGEM U. S. S. R. Academy of Sciences).

36 crystalloclastic porphyritic tuff [11].
39 brecciated lava with almond-shaped lenses of calcite [11].
67 diabasic tuff with volcanic bombs [11].

Table 3

Chemical Analyses of Acid Dikes

Composition	Weight per cent				Numberical characyeristics according to A. N. Zavaritskiy				
	38^b	70	$0\text{-}35^1$	$0\text{-}38^a$		38^b	70	$0\text{-}35^1$	$0\text{-}38^a$
SiO_2	73.72	74.62	74.46	75.58	a	14.2	12.1	15.1	12.1
TiO_2	0.36	0.03	Trace	0.30	c	1.7	1.4	0.7	1.5
Al_2O_3	13.63	11.72	12.89	12.70	b	2.5	5.5	1.3	3.2
Fe_2O_3	1.42	3.18	0.35	2.00	s	81.6	81.0	82.9	83.2
FeO	0.91	1.58	0.60	0.00	f'	78.95	73.8	85.0	54.16
MnO		0.05	0.22	0.14	m'	18.42	23.8	15.0	4.16
MgO	0.28	0.82	0.14	0.06	c'	2.73	2.4	0.0	—
CaO	1.50	1.43	0.54	1.30	a'	—	—	—	41.66
Na_2O	5.29	4.52	4.12	3.27	n	79.43	78.5	56.9	57.61
K_2O	2.07	1.87	4.70	3.75	t'	0.40	—	0.03	0.32
H_2O^+	0.55	0.19	0.27	0.79	φ	47.36	4.8	30.0	50.00
H_2O^-	0.00	0.17	0.00	0.00	$\frac{a}{c}$	8.3	8.6	21.6	8.1
Ignition loss	0.23	0.28	—	0.43	Q	+33.1	+36.2	+34.9	+40.7
Total	99.96	100.45	100.29	100.32					

38^b plagiogranite porphyry; dike in the Sinyushinskiy granitoid massif (second intrusive stage) . V. Klitina, analyst (IGEM U. S. S. R. Academy of Sciences) .

70 felsite porphyry; dike located to the west of the southern peak of Mount Chashiny [11] , buried in the Devonian deposits (second stage) .

$0\text{-}35^1$ spherolitic porphyry; dike located in the Sinyushinskiy granitoid massif (second stage of intrusion) . Analyst, V. Klitina (IGEM U. S. S. R. Academy of Sciences) .

$0\text{-}38^a$ microporphyry; the dike cuts across the second-stage plagiogranite porphyry dike (microporphyritic stage) . Analyst, V. Klitina (IGEM U. S. S. R. Academy of Sciences) .

Zavaritskiy's classification, belong to the class of oversaturated SiO_2 rocks and to the alkali-rich group. Constitutionally the rocks closely resemble one another. Yet, there still are some distinctions. For the rocks of the second intrusive stage (samples $0\text{-}35^1$, 38^b, 70) these distinctions consist in different contents of femic components (ferric and ferrous oxides, magnesium, calcium) and potassium. The differences in the former are negligible. As seen from the description, they do not affect the mineralogic composition of the rocks and are, in all probability, attributable to the influence of the medium. Thus, one of the dikes of the second stage which is buried in the Devonian deposits (Sample 70) differs most of all from the two other dikes of the same second stage by its Fe-Mg content. Distinctions in the potassium content between the second-stage dikes are attributable to their freshness. Potassium is to be found in greater quantities there where the unreplaced insets of potash feldspar are still preserved (sample 0.35^1). This circumstance emphasizes the similarity between the well preserved second-stage dikes and the microporphyry dikes.

As to the dike of the microporphyritic stage (sample $0\text{-}38^a$), regardless of its younger age as compared with the three other dikes, the differences in chemical composition are also negligible. They concern mostly the ferrous oxide which is altogether absent, and magnesium whose role is insignificant. These peculiarities may be explained by the fact that this dike is buried in acid rocks of similar composition, and is relatively unaltered.

The figurative points pertaining to the composition of all rocks fall close to one another. Moreover, the vectors of contemporaneous rocks (second stage) exhibit almost identical lengths and inclinations. The vector of the younger dike differs from the first three. It deflects sharply to the left in the direction of the SB axis and characterizes the rock as being oversaturated with silica. This is in good accord with the increased content of muscovite-sericite as compared with other acid dikes.

From the recorded chemical characteristics, the following conclusions may be drawn. 1) The series of basic dikes is formed by one and the

...e magma. The variations in the composition
...he dikes of different intrusive stages are
...ligible and are successively regular. They
...ect the evolution of magma in time in the
...ection of the enrichment of the more recent in-
...ions by salic components. In terms of com-
...tion the magma closely approaches to that
...lkalicized basalts and lamporphyres, and
...ers from the pure-line gabbro magma. 2)
... dikes of the acidic series are formed by
... and the same magma. Variations in the
...position of the dikes of both stages are
...ligible.

CONCLUSIONS

...A complex of dikes was identified in the Len-
...gorsk region, both of basic and acid compo-
...on and independent from the masses of gran-
...ds and other igneous rocks. The formation
...his complex of dikes occurred over a long
...iod of time. Several stages of intrusion
...e discovered in this complex. All the basic
... acid dikes originate separately from a con-
...utionally similar magma. The intrusion of
...es occurred alternately. This justifies the
...umption of a simultaneous existence of two
...arate centers (pockets) of magma of differ-
... composition.

...The basic dikes cut across the youngest of
... Kalbinskiy granitoids existing in the area in
...stion. Thus, they (most probably, only their
...st recent part) constitute the youngest in-
...sive formations in the region.

...This identified basic dikes correspond to the
...nor intrusions, as defined by Yu. A. Bilibin
...and F. K. Shipulin [8], of the late stages in
... tectonic-magmatic development cycle of
...bile belts.

...Minor intrusions of basic composition possess
...nilar chemical features which distinguish them
...m other igneous rocks formed by basic magma.

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JOINTING AND SECRETIONS IN BASALTS OF NORTHERN TIMAN[1]

by

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INTRODUCTION

In the studies of the northern Timan basalts (figure 1) conducted for two years by the Northern Base of the U. S. S. R. Academy of Sciences, the author's special attention was devoted to the joints and secretions in basalts. Hence, this subject has become the main topic of the present paper.

The geology of the investigated region is described in detail [3-5], and we shall, therefore, refer to it in the briefest possible form.

It has been believed that the basalt flows in northern Timan occur at the contact between the Middle and Upper Devonian [5]. F. N. Chernyshev [7] considered all the Devonian deposits here, including the porphyritic extrusions, as belonging to the lower sections of the Upper Devonian. A. A. Chernov [6], on the other hand, identified only two Devonian formations: a lower one, represented by sandstone with subordinate schist and conglomerate, and an upper one, consisting of schist and sandstone. He assigned the lower formation to the upper part of the Middle Devonian, the lower - to the Frasnian stage of the Upper Devonian. All the superficial basaltic extrusions enclosed between these two strata were considered by him as of Upper Devonian age.

On the basis of the material produced in the most recent investigations in northern Timan, I believe it possible to identify three Devonian formations: the lower, overlying the more ancient and only recently discovered basalts; the middle one, which is contemporaneous with the bulk of the basaltic flows and which is assignable to the lower sections of the Upper Devonian; and, finally, the overlying upper formation.

Thus, there appear to be two phases of basaltic extrusion. To the first more ancient phase of Middle Devonian age we assign the basalts exposed in Chaytsyny Nosy, on the Chernaya River and the basalt outcrops located on the Belaya River below the estuary of the Kumusrki-Beloy. This latter bed is buried under a 180-m thick series of Middle Devonian sandstone and conglomerate.

The absence of the sandstone and conglomerate series west of Chaytsyny Nosy, near the Upper Silurian outcrops, A. A. Chernov attributes to the existence of a fault. He writes: "There are grounds to suppose that the contact between the Upper Silurian formations and the basalts is abnormal here and probably assumes the form of a fault, with the basalts representing the down thrown side". He sets forth a number of arguments in support of his theory and admits that it is possible that there was no pre-basaltic Devonian deposition in this region where the Upper Devonian basaltic lava has flown directly over the Silurian deposits.

Thus, A. A. Chernov does not believe that there were two phases of basaltic extrusion in northern Timan. However, since basalts were revealed by us in the region of Belaya River under a thick formation of sandstone and conglomerates belonging to the upper sections of the Middle Devonian, we feel justified in our assertion that two phases (separated in time) of basaltic extrusion must have occurred in this region. With this conclusion in mind, there is no need to resort to the theory of disjunctive dislocations with regard to the Chaytsyny Nosy area. The direct bedding of basalt over the Silurian deposits observed by A. A. Chernov near the river Chernaya, may be explained by lack of sedimentation of Middle Devonian sandstone, and the fact that the area was highly disjointed in Late Devonian time.

The subdivision of the Devonian deposits into three series is based on differences in mineralogic composition. The middle Devonian formation differs considerably from the lower and the upper strata, in which grains of staurolite and almandine were found to be present in large quantities.

Through observation of joints and secretions in basalts it has become possible in the course of
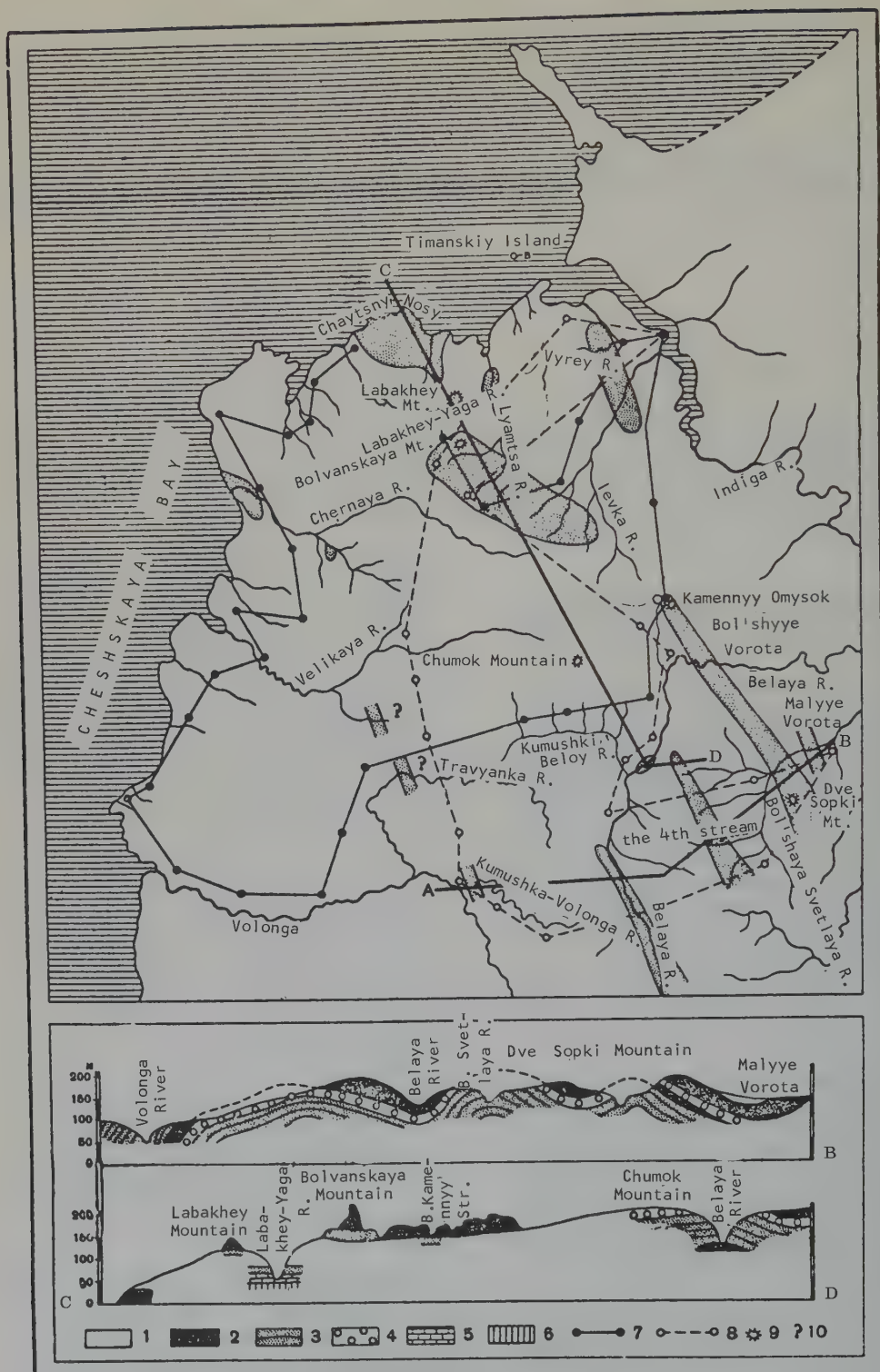
Fig. 1. Map showing the occurrence of basalts in northern Timan

1 - Quartenary deposits, 2 - basalt, 3 - Devonian sandstone, 4 - Devonian conglomerate,
5 - Silurian limestone, 6 - pre-Silurian quartzite, 7 - first year's route, 8 - second
year's route, 9 - mountains, 10 - probable outcrops of basalt.

field survey to reveal 12 basaltic flows located adjacent to one another in a single section. An exceptionally clear example is provided by the Malyye Vorota section at the Bol'shaya Svetlaya River where boundaries were established between the basaltic flows during a survey of jointing.

Petrographic analysis of the samples taken at the bases of the flows and carried out by B. M. Kupletskiy [1] showed that all of them were characterized by compact basalt with intersertal texture, relatively poor in glass, and by finely crystallized constituents. The samples taken from the upper parts of the flows were described as vitrophyric basalts rich in glass, abounding with cavities and lenses, and poor in crystalline deposits of plagioclase and pyroxenes.

Thus, the separation of basaltic flows based merely on the study of jointing and secretions turned out to be correct.

Failure to take into consideration the character of jointing and secretions encountered in the flows has lead many investigators to erroneous conclusions that the basalt of several flows embedded one upon another constitute a single flow. For example, in the Bol'shyye Vorota canyon of the Belaya River, F. N. Chernyshev was able to recognize only two basaltic flows separated by sandstone. He failed to identify the basaltic flows clustered one on top of another and considered them as a single flow.

In other instances, samples of basalt were taken without reference to the exact section of the flow from which they were cut. This caused the authors to draw erroneous conclusions as to the time of extrusion of the basaltic flows in northern Timan [2].

As a result of the survey it has become evident that the area of basalt occurrence in northern Timan is considerably smaller than estimated by F. N. Chernyshev (Figure 1).

TYPES OF JOINTING

Field observations have shown in most cases that the various types of jointing, as well as the shapes of cavities in the basalt correspond to definite parts of the flow [1].

All structures in the basalts of northern Timan may be subdivided into several types.

1) Columnar structure inherent to compact basalt with rare and large secretions.

2) Spheroidal jointing which may be broken down into three subtypes: a) large spheroids of identical size made up of compact basalt with rare and large secretions; b) concentric-conchoidal structure: basalt less dense than subtype "a", but with a large number of deposits usually orbicular in form; c) complex spheroidal jointing characteristic of compact basalt with rare small and large secretions, typified by a combination of large spheroids breaking down into smaller ones.

3) Pillow-like jointing. The basalt is not dense and contains a large number of cylindrical, tabular, and spheroidal small and large secretions.

4) Sheet structure, which may occur in dense basalts without any deposits and in the vesicular variety with fine deposits.

5) Basalt without jointing but fissured: a) compact, without fine deposits, but often containing a large number of major secretions; b) vesicular, with a large amount of fine deposits usually of spheroidal shape and with lenticular secretions; c) spongy, with cavities and deposits of medium size, most frequently irregular in form.

1. Columnar Jointing

Columnar structure may occur only at the base of a basaltic flow if it is more than 10 m thick. It begins a few meters away from the base, less frequently at the very base of the flow (Figure 2).

In the majority of cases, jointing of this type is directed vertically, perpendicular to the base, and most frequently displays a structure of large columns. However, quite often one may observe a deflection of the columns in one direction or another. In certain cases, their position is related to the conditions of the lava-congelation process, as may be seen in Figure 3, where they exhibit a gradual bending. The greatest deflection is usually characteristic of the thinner columns. Fairly often the columns spread in a fan-like pattern forming the so-called, radial-fibrous columnar structure. In other instances the inclination of the jointing is related to secondary processes, namely, to the general inclination of the basaltic flow which was subsequently dislocated. In this case the columns are more frequently arranged perpendicular to the dip plane of the flow.

The diameter of the columns ranges from 0. 1 to 2m. As a rule, the large diameters occur at the bottom section of the basaltic flows. Upward tapering of the columns may sometimes be observed. In other instances, sharp transition from thick to thin columnar structure occur.

FIGURE 2. Contact of two basaltic flows at Chaytsyna Stream

The columns are usually penta- or hexa-hedral, less frequently tetrahedral, and very rarely trihedral. The polygonal shape is expressed better in thick columnar structures than in those with thin columns. The thick columns sometimes display horizontal cracks (see Figure 3), often with bulging faces. In other places elements of the orbicular structure may be observed in thick columnar jointing. However, the former is less pronounced than the later. Upwards from the bottom of the flow, columnar jointing usually gradually disappears and the rock becomes fissured without jointing. In other instances, it becomes possible to observe a sharp boundary between columnar structure and basalt free from jointing (see Figure 3).

2. Spheroidal Jointing

The first type of spheroidal structure was found in compact basalts with rare fine deposits in several basaltic flows in the Malyye Vorota canyon of the Bol'shaya Svetlaya River, at the bottom of the third basaltic flow in the upper reaches of Belaya River, and at the bottom of the first and the upper part of the third flow on the banks of the Kumushka Volonga River (Figure 4).

The diameter of the spheroids ranges from

0.2 to 1 m. The larger orbs are more often found at the bottom of the flow. In most cases the lumps do not have a regular spherical shape, but display a certain angularity. Basalt with orbicular jointing characterizing the upper part of the flow is usually less compact, and contains in places a large amount of fine deposits. The thickest basaltic formation (about 10 m) with spheroidal jointing was encountered in the upper section of the third flow at Kumushka-Volonga River.

The concentric-conchoidal structure constitutes the second type of orbicular jointing.

It has been found only in one spot: on the left fourth stream emptying into the Bol'shaya Svetlaya River opposite Dve Sopki Mountain. By its general aspect, this structure differs sharply from the first type, even though it has a fairly distinct orbicular shape and usually a varying size of spheroids. Very conspicuous is the internal structure of the jointing. Disintegration of the rock into shell-like fragments (Figure 5).

Regrettably we ignore both the thickness and the pattern of direct transition of this structure into the other types. Consequently, we cannot say with any amount of assuredness to what part

FIGURE 3. Slight bending of the columnar structure. Basalt on the top reveals fissures but no jointing

FIGURE 4. Spheroidal jointing in the basalt formation
at Kumushka-Volonga River

of the basaltic flow this particular structure corresponds. Judging by the rock itself, in which many small secretions were encountered, it must, apparently, be attributed to the upper layers of the flow.

Indications may be found in literature to the effect that this type of jointing is formed as a result of erosion of spheroidal structures. In other words, its conchoidal texture represents a secondary formation.

The third complex-spheroidal type of jointing occurs in the upper layers of the second basaltic flow at Kumushka-Volonga River. This type differs from the first variety in that the original spheroids break up into a series of smaller orbs when hit by a hammer. The smaller orbs do not split and consist of dense basalt with rare fine deposits. Owing to this property, orbs of various diameters, ranging from 0.05 to 1 m, may be found on the slope.

The thickness of the basalt formation with complex-spheroidal jointing is 10 m.

3. Pillow-Like Jointing

This type of jointing occurs in the second

basaltic flow in the upper reaches of Belaya River (Figure 6) and in the first basaltic flow at Kumushka-Volonga River. In both bases, the pillow structure coincided with the uppermost layers of the flows.

The structures constitute elongated pillow-like shapes up to 1 m thick and 2 m long placed one on top of another. In spots they have well pronounced bulging and smooth upper surfaces and concave lower faces. Moreover, all the structures have their rounded lower ends turned in the same direction.

4. Sheet Jointing

Basalt with sheet jointing occurs in the upper reaches of the Belaya River, in the Malyye Vorota canyon, in the Bol'shaya Svetlaya River, and Kumushka-Volonga River. Ordinarily, this structure occurs in the upper part of basaltic flows. The sheet structure is characterized by the presence of parallel fissures which split it into "sheets" up to 2 m thick. The joints are oriented horizontally, or they are inclined if the layers are dislocated, but they always run parallel to the surface of the basaltic flow.

On the sea coast in Chaytsyny Nosy, sheet
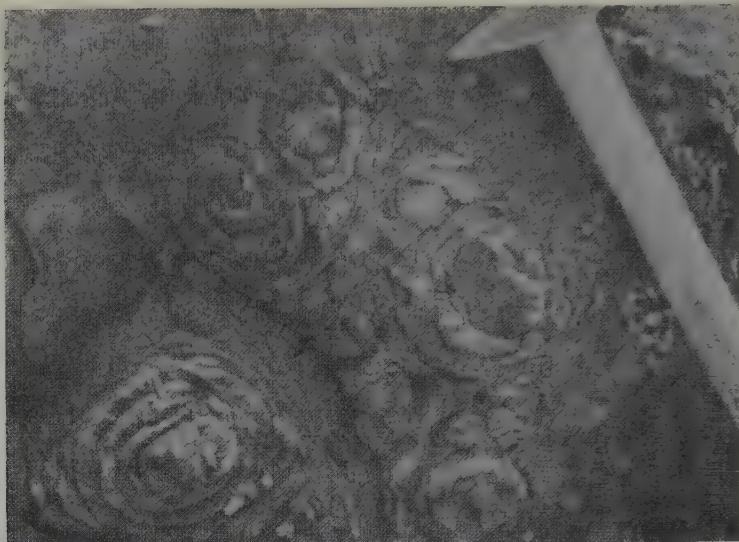
FIGURE 5. Concentric-conchoidal jointing in basalt

structure is developed in compact fissured basalt which represents the middle or the lower part of a basaltic flow. Shown in Figure 7 is a basaltic formation split by horizontal joints running 1 to 2 m apart.

5. Fissured Basalt Without Jointing

Basalt without jointing may oftentimes be encountered in all layers of the flow. Quite frequently it is possible to observe a basaltic flow parted by numerous differently oriented joints (see Figure 3). Ordinarily, jointing cannot be traced in thin basaltic flows. As mentioned above, the cracks in basalt are usually oriented at random following a tortuous course. Sometimes, however, they display a more regular pattern of orientation. In the upstream region of the Belaya River, for example, measurements were made of cracks, the planes

FIGURE 6. Pillow-like jointing in basalt
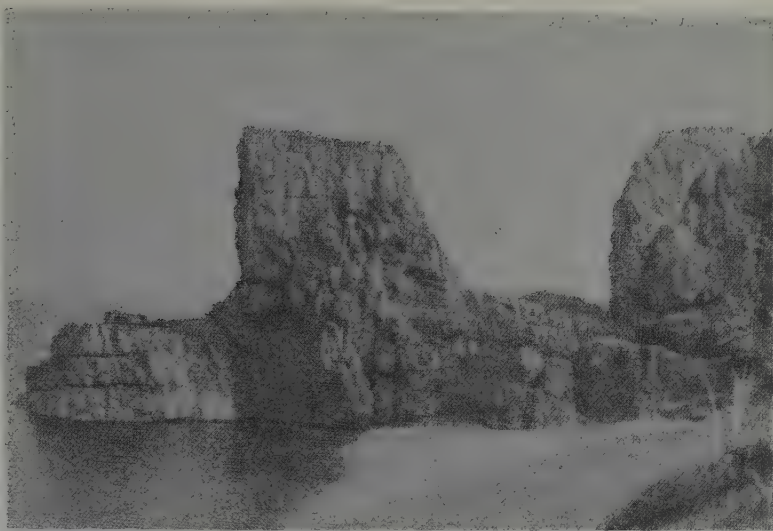
FIGURE 7. Sheet jointing in basalt at Chaytsyny Nosy

of which dip 265° to the southwest at an angle of 70°, 360° to the north at an angle of 47°, and 180° to the south at an angle of 27°. Owing to this fact, dense basalts usually split up into sharp-angled lumps. Well-developed vertical cracks running from west to east may be observed in places, as for example in Chaytsyny Nosy (Figure 7).

SECRETIONS AND THEIR STRUCTURE

Basaltic flows in most cases contain both large and small secretions, the size and the shape of which depend on the part of the basaltic flow in which they occur. At the base layers of flows secretions of loaf-like or conical shape are most common (Figure 8; 1-7). Fine secretions are very rarely found in basalts with columnar structure. Whenever they are encountered, they usually have the shape of a small ball, more frequently 3 to 5 mm in diameter, or a small almond (Figure 8; 10, 11). These almonds consist of a light bluish chalcedony.

A large quantity of cylindrical deposits, normally composed of calcite (Figure 8; 28), sometimes together with delessite (Figure 8; 30) may be found at the very bottom of basaltic flows. The cylindrical formations are elongated upwards. Sometimes they extend from the very base of the flow (Figure 8; 28), in other instances they appear at a little distance from the bottom (Figure 8; 30). Large deposits, secretions are also rare and are mainly encountered in thin-columnar structures. More often they have a coniform shape with the taper always facing upwards (Figure 8; 3, 4, 7, and 9). Sometimes

the shape is loaf-like (Figure 8; 1, 2, 5, 6, and 8). Certain types of flat secretions attain 30 cm in diameter and are made up of agate, chalcedony, crystals of transparent (Figure 8; 1) or smoky quartz (Figure 8; 8), or amethyst (Figure 8; 6). Quite frequently all types of SiO_2 modifications may be encountered in one and the same secretion, sometimes with calcite crystals and barite laths (Figure 8; 5). All secretions, as a rule, have a chalcedony envelope. The number of secretions in basalt with columnar joinging seldomly exceeds one or two per 3-5 m^2.

In basalts with spheroidal jointing large secretions are in general very rare at the base of the flows. They usually have varying shapes: conical, flat, and irregular. In the bottom sections of the pheroids abutting upon the underlying rock, the secretions are always of cylindrical form. In the next row of spheroids no cylindrical deposits are to be found at all.

Basalt in pillow pointing is of the porous variety with frequent fine secretions or almonds, the larger deposits having a cylindrical shape with a diameter of 0.5 cm and a height of 5 cm. They are arranged perpendicular to the lower surface of the structure and extend upwards from it. In the middle section of the structure, the secretions are smaller in size and have an irregular shape, less frequently, spheroidal. Near the convex surface they become even smaller, usually assuming a flat form. They are situated parallel to the surface of the orbs.

Basalt with sheet structure, in the upper
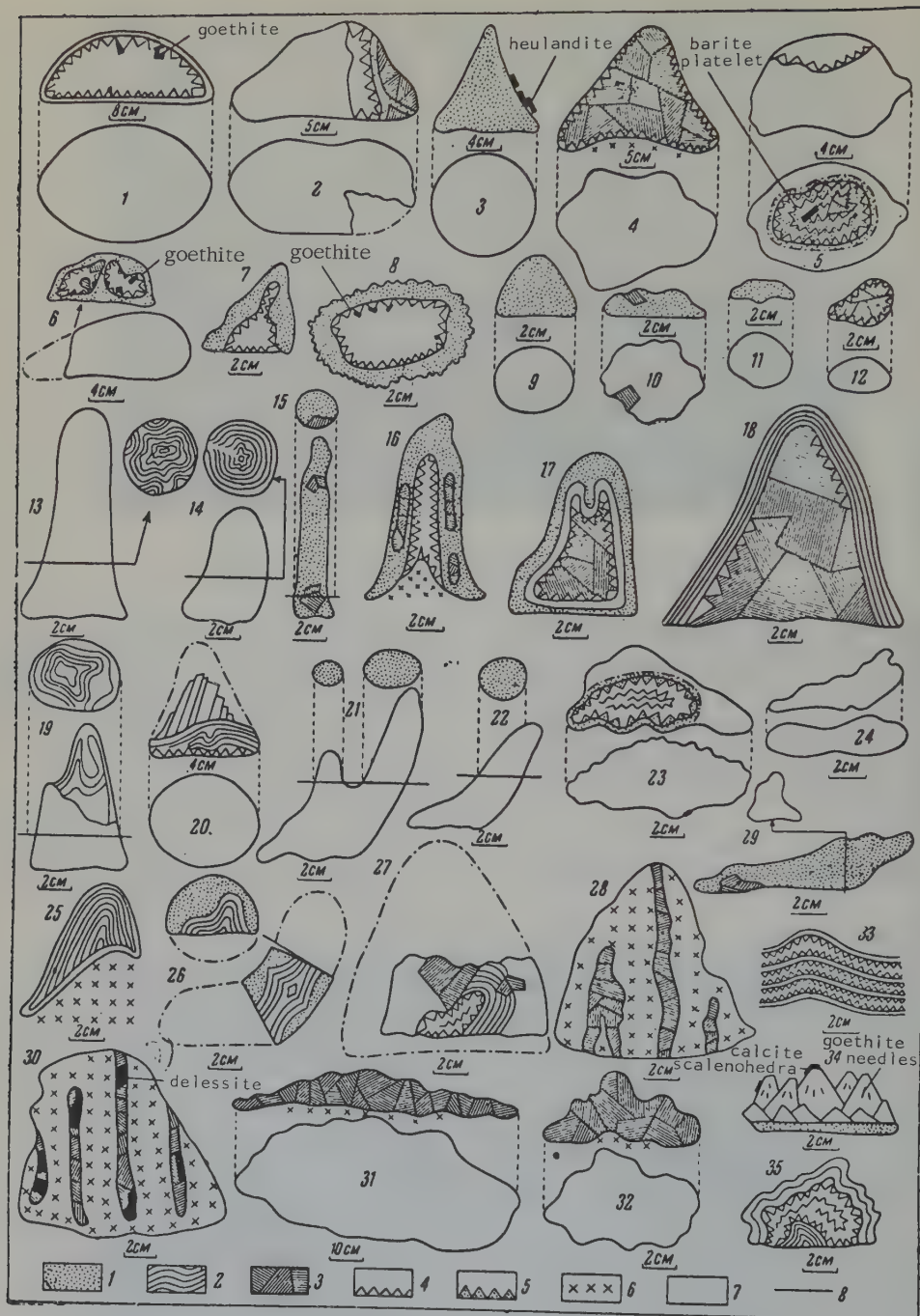
FIGURE 8. Shapes of secretions in basalts and their internal structure. Sections of
secretions show their side view and their location in a basalt flow. Projections,
designated by numbers, illustrate the appearance of the secretions viewed from above.

1 - chalcedony; 2 - agate; 3 - calcite crystals; 4 - quartz crystals; 5 - amethyst crys-
tals; 6 - basalt; 7 - cavities within the secretions; 8 - cross-section of secretions
(figures in the pictures correspond to the references in the text).

layers of the flows, contains a large number of fine secretions, usually regular in shape. Their quantity at times is so considerable that the percentage representing the basaltic mass itself is by far inferior to that corresponding to the secretions. Large lenticular secretions sometimes formed entirely of calcite crystals may frequently also be found here (Figure 8; 31, 32). O tentimes, the walls of large secretions of irregular form turn out to be overgrown with crystals of quartz, calcite, and well-pronounced pink analcime crystals. In most cases basalt without jointing contains a large amount of both large and small secretions.

In addition to the described conical and laf-shaped secretions embedded in the lower layers of basaltic flows, elongated secretions also appear in the middle layers (Figure 8; 13-17) extending vertically and very rarely horizontally (Figure 8; 29). Sometimes they are bent, with their lower end set horizontally, while the upper end, gradually bending, is directly vertically (Figure 8; 21, 22, 24 and 26). Some of the conical secretions have a bent in the bottom (Figure 8; 6), whereas their structure may be very different as can be seen from Figure 8.

Characteristic of all secretions, regardless of their shape, with the exception of cylindrical deposits, is their almost invariably wider base than apex. A large accumulation of such secretions occurs in the middle layers of the flow. Here, basalt is usually free from jointing, although fissured; it is compact and has sparse fine secretions. In certain places the number of large secretions reaches five per 1 m^2. Occasionally the secretions are located close to each other in horizontal rows separated by 1-m intervals. Their shape is flat and irregular in places. In sizes they range from 1 to 6 cm and occur in quantities of up to 25 per 1 m^2 (Figure 8; 9, 10, 11 and 12).

Upwards from the flow's middle layers, the number of secretions diminishes. In the upper layers, the rock becomes spongy and abounds in fine deposits. The secretions here are usually irregular, oftentimes of the small variety (Figure 8; 31 and 32) consisting mainly of calcite crystals and sometimes of fairly transparent iceland spar. Some lenses may attain 20 cm in thickness and 1 m in length. They are located parallel to the surface of the basaltic flow.

A large proportion of small, irregularly spheroidal secretions occur in the uppermost layers of the flow. These small, almond-like deposits, ranging in size from 1 cm to microscopic sizes, are made up of various minerals. The most frequently encountered are chlorite, calcite and palagonite.

Some secretions, as we have already seen (Figure 8), are entirely composed of light-bluish chalcedony (Figure 8; 3, 9, 11, 21, 22 and 24). Some of them display fine crystals of calcite which are located along the edges (Figure 8; 10, 15 and 29) and very rarely inside the chalcedony (Figure 8; 16). In large-size secretions, chalcedony constitutes the peripheral part, whereas crystals of smoky quartz (Figure 8; 1, 7) and of amethyst (Figure 8; 5 and 6) are to be found in the middle. Chalcedony sometimes changes into agate towards the center of the secretion (Figure 8; 17 and 26). Purely agate secretions with alternating light-bluish, light-grayish, and milky white streaks may be observed fairly often (Figure 8; 13, and 14, 19 and 25). Sometimes they are distinctly expressed, in which cases they usually cleave easily along the rings (Figure 8; 18). Other agate secretions, even though they also have a concentric structure, produce sharp-angled fragments with conchoidal fracture upon splitting. The thickness of the streaks ranges between 0.25 and 5 mm. Some of them show rings (Figure 8; 14) in cross-section. These rings are bent out in one place in the direction of the secretion wall indicating the location of the original hole in the secretion. In other secretions the streaks follow a winding pattern in by-passing all the inside wrinkles (Figure 8; 13).

The quartz crystals usually fill the central part of secretions. Sometimes, however, they are arranged along the periphery, with crystals of amethyst located closer to the center (Figure 8; 5). Cases where crystals of amethyst are on the periphery and quartz is in the center are to be observed very rarely (Figure 8; 23).

Crystals of smoky quartz and amethyst with clearly defined faces occur also in hollow secretions. In these cases some of the quartz and amethyst crystals may contain deposits of goethite (Figure 8; 1) which in the form of small needles is observable inside the crystals. Here, it is possible to discern sharp scalenohedra of calcite on the crystals of smoky quartz.

Calcite crystals may be encountered fairly often in secretions. In the majority of cases they completely fill in their centers (Figure 8; 4, 5 and 12, 17 and 18) or the entire secretions (Figure 8; 28, 31 and 32), sometimes the peripheral parts of them (Figure 8; 2). As a rule, calcite was last to crystallize, but in some cases its crystallization occurred at an earlier stage (Figure 8; 2 and 27). In these instances, the faces of the crystal are well defined and overgrown with quartz on all sides (with the exception of the bottom face).

As revealed by analyses, the calcite crystals

are penetrated by fibrous crystals of ptilolite insoluble in HC1. This makes them unsuitable for use in optics. In certain secretions, which are usually filled only with chalcedony, the crystals of calcite are located in the marginal sections (Figure 8; 10, 15 and 29). Barite laths (Figure 8; 5) occur very rarely here. Crystals of heulandite were found in basalt near the secretions (Figure 8; 3), while desselite was found in cylindrical secretions (Figure 8; 30).

Apart from secretions filled by a variety of minerals, veins were also found to be present in the investigated basalts. They may be broken down into three categories.

Veins of the first category are usually found to be running vertically in some definite direction. Their thickness remains constant over a certain distance. Usually these are quartz veins, or chalcedonic and palagontitic, enclosing crystals of quartz, amethyst, and rarely of calcite (Figure 9; 1). Calcite crystals sometimes are encountered in the middle section of the vein for a considerable distance along its length (Figure 9; 2). Microscopic examinations reveal that the calcitic-chalcedonic filling in the peripheral part of such veins contains angular, irregular fragments of altered basalt. This category of veins is usually unrelated to any particular basaltic flow alone and cuts through the adjacent formation as well. Copper inclusions are associated with these veins.

The second-category veins have no definite orientation, they vary sharply in thickness, and taper out altogether after running for a short distance. Such veins are usually located in the middle or upper parts of the flow and consist of calcite crystals, pinkish or greenish in color. The milky white crystals are not transparent. Druses of quartz (Figure 8; 7) and chalcedony (Figure 8; 5 and 6) may be observed in the central part of calcite veins.

Veins of the third category are developed along the joints of the structures, and are rather rarely encountered. A good example of such veins constitute the gangues around the columnar jointing on the sea shore north of the estuary of Cheranya River. They do not exceed 0.5 to 1 cm in thickness.

In the Bol'shyye Vorota canyon of Belaya River, veins of fibrous calcite may be observed between the structural columns of the first lower
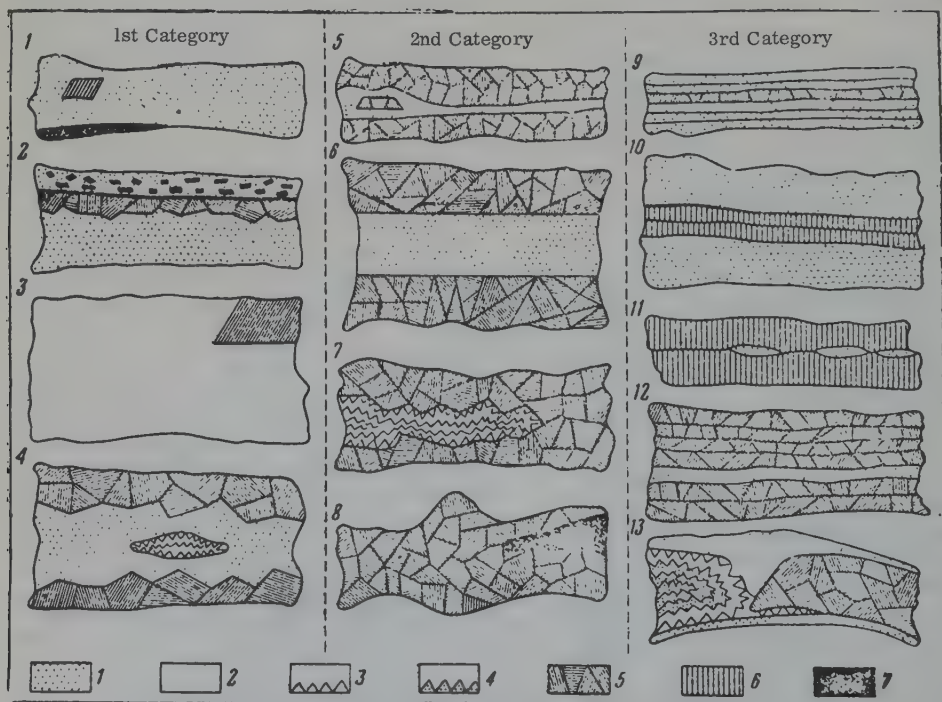

FIGURE 9. Texture of the veins encountered in basalts

1 – chalcedony; 2 – quartz; 3 – quartz crystals; 4 – amethyst crystals; 5 – calcite crystals; 6 – fibrous calcite; 7 – basalt. The figures in the picture denote the sample numbers.

flow (Figure 9; 10 and 11). A more complex structure is displayed by veins between the elements of spheroidal jointing. These veins consist of calcite, amethyst, and quartz crystals. Among such veins, one may often encounter the calcite-chalcedonic variety made up of alternating colored bands of chalcedony and calcite (Figure 8; 9 and 12).

CONCLUSIONS

All the structures in basalt described herein mostly correspond to a definite section of the flow. As shown by observations, this relationship depends, on the thickness of the formation, and on the nature of deposits underlying and overlying the basaltic flow.

According to our observations, the thickness of the flow is the main factor conducive to the formation of columnar jointing. The thicker the flow, the more developed is the columnar structure. Moreover, the diameter of the columns is greater at the bottom than in the upper part of the flow. No inverse relationship has even been recorded. Columnar jointing gradually disappears with height. Often it changes into radial-fibrous thin-column structure in the middle layers of the basaltic flow. This type of structure may also occur at the base, but in this case it is poorly defined and develops in thin flows. The development of columnar jointing only at the base of basaltic flows points to the fact that the congelation of lava proceeded very gradually. The slower the process, the thicker the columns formed. The development of radial-fibrous columnar jointing should be, apparently, associated with uneven congelation of the basalt, which may cause the columns to slope strongly in one direction or another.

The appearance of spheroidal structure in columnar jointing may be attributed to the efflux of a powerful basaltic flow into a water reservoir. In such cases, typical spheroidal structure could not have formed due to high pressure.

Absence of any jointing in the upper parts of the flows must, it seems, be related to rapid congealing of lava.

In those cases where the basaltic flow overlies argillaceous deposits, spheroidal jointing is always registered in its bottom section. If, on the contrary, the flow is bedded on top of sandstones, no orbicular jointing is to be observed. As previously mentioned, spheroidal structure was encountered in the upper section of the flow, and here it is covered by argillaceous formations.

The appearance of spheroidal jointing in the upper layers of the flow leads to the conclusion that it must have been entirely submerged in a water reservoir and that clayey material settled over it.

Often enough orbicular structure may be registered at the base of a basaltic flow directly overlying another flow. This relationship seems to contradict our theory. But this may be explained by the fact that the efflux of basaltic lavas, which has occurred here in a water medium, must have proceeded so rapidly that there was no time for deposition of argillaceous sediments. These were, apparently, the conditions under which extrusion of basaltic flows must have taken place in the Malyye Vorota canyon of the Bol'shaya Svetlaya River, where the greater part of the basaltic flows manifest spheroidal jointing at the base.

Lack of orbicular structure in the upper part of Malyye Vorota may be attributed to the fact that the water reservoir, into which this flow was discharged, must have been, in all probability, rather shallow, so that the upper section of the flow has never been submerged. Another explanation may also be possible, if one is to assume that the basaltic flow was totally submerged. Spheroidal jointing under these conditions could not have developed since after a short interval, a second flow was discharged on top of the still not entirely solidified lower flow. This should have upset the favorable conditions for the development of spheroidal jointing in the upper part of the underlying flow. However, this explanation fails to clarify the fact that orbicular structure was not registered at the bottom of other basaltic flows exposed in Malyye Vorota. More probably is the first explanation which follows from the assumption that the extrusion of basaltic flows in Malyye Vorota occurred in shallow water reservoirs which have totally disappeared with time.

The character of sediments in the middle series of the Devonian formations to a certain extent indicates that the water reservoirs must have been shallow and not permanent. It is to be regretted that there is so little published information on the formation of spheroidal jointing in basalts. Only one thing is known, that it is, apparently, characteristic of underwater extrusions. Some kind of relationship, no doubt, exists between spheroidal jointing at the base of the flows and argillaceous formations. Of course, it is not always true that clay deposits indicate that the extrusion of basalts has taken place in aqueous conditions. It may have occurred considerably later when the water body dried up. In this case, it is possible that moisture which was contained in the argillaceous formation was sufficient for the development of orbicular structure, whereas in arenaceous deposits the moisture content was insufficient for this purpose.

The thickness of the zone with spheroidal jointing at the bottom of the flow may, as we

see, be different, but its maximum thickness is to be observed in rather thin basaltic flows.

The development of concentric-conchoidal jointing is, as previously noted, associated with the process of erosion of the spheroidal structure, i. e., the conchoidal structure is a secondary formation. Secondary processes are, apparently, also responsible for the formation of complex-spheroidal jointing.

Pillow-like structures are characteristic of the upper layers of the flow and their formation, we feel, must have occurred in the following manner. In the process of extrusion, there appeared with time a crust on the surface of the flow. Under the pressure of lava, cracks developed in this crust, through which semi-congealed pillow-like formations were squeezed and laid one on top of one another. Each such formation constituted a kind of a small basaltic flow; each settling in the form of a layer over the preceding layer with the lava not yet fully solidifed.

If our reasoning is correct, then we must find in pillow jointing all such indications as are characteristic of basaltic flows. A petrographic determination of basalt taken from one such structure showed that, in spite of the fact that this structure corresponded to the upper layer of the basaltic flow, the type of the rock in various parts of this structure was found to be different. Samples taken from the bottom of these small "flows" turned out to be basalt which is usually typical of the lower part of a flow. Samples cut from the surface proved to be vitrophyric basalt characteristic of the upper part of flows. Thus, petrographic examination of the pillow structure confirms that it represents what one could call an independent, small basaltic flow. This is also evidenced by the presence in the bases of these small flows of cylindrical cavities which are situated perpendicular to the usually concave lower surface. As already mentioned earlier, these types of secretions are to be found only at the very bottom of basaltic flows and are known to be formed by bubbles of vapor during the extrusion of a flow onto a moist surface.

The development of sheet jointing in the very top layer of the second basaltic flow in the upper reaches of Belaya River, appears to us to be similar to the formation of pillow-like jointing.

The sheet structure developed in compact basalt and observed by us at the seashore (Figure 7) is, no doubt, related to the primary processes of flow congelation. Apart from this, sheet jointing may also develop as a result of liquid magma action on the underlying basaltic flow.

The differently shaped secretions also correspond to definite parts of flows. Secretions of cylindrical form are observable at the bottom of both the flows and the zones of pillow jointing which form in the upper part of a flow. In the lower and middle sections of flows predominant are loaf-like and conical secretions, in the upper parts, secretions of lenticular and irregular shape.

As to the filling of basaltic cavities, no relationship has been established so far between the mineralogic composition and any particular section of the flow. It is only possible to note that zeolites are more common in the upper part of the flow and in basalt located near fault lines.

A survey of jointing and secretions in basalts enables the geologist to determine fairly accurately to what part of a flow a given outcrop of basalt corresponds, if the contacts with the overlying and underlying rocks are not directly visible. Moreover, without such observations it would have been hardly possible to identify such a number of basaltic flows as are exposed in one section in Malyye Vorota of the Bol'shaya Svetlaya River where they are layered one on top of another.

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EXTRACTION OF CARBONATE ADMIXTURES AND CARBONATE CEMENT FROM ROCKS BY ELECTRODIALYSIS[1]

by

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1. Introduction

The common methods of freeing rocks from admixtures of carbonate material or carbonate cement are based on treatment of samples by diluted acids, usually 2 to 5% hydrochloric or, less frequently, acetic acid. However, acid processing leads to partial, and sometimes total, dissolution of a number of mineral constituents which it may be necessary to preserve in unaltered state for further investigations. This concerns such minerals as apatite, many zeolites, sepiolite, chlorites and other varieties.

The effect of acids on various minerals depends on many factors and leads to different results. Many minerals are practically insoluble, or soluble to such an insignificant a degree that for purposes of regular mineralogic analysis the effect of acid on them may be disregarded. A fairly large number of rock-forming minerals as, for example, feldspars, amphiboles, kaolinite, and a few others, dissolve only in negligible amounts. Moreover, the solution process affects the surface layer of the mineral from which a proportion of the components is removed fairly rapidly, whereas the remaining silica forms an exceedingly thin film preventing the penetration of acid into the inner zones of the mineral. Consequently, in the absence of mechanical or any other action capable of destroying the protective film, the process of practically to an end. The thickness of the protective films is considerably smaller than the microscope's power of resolution and does not affect the optical properties of the investigated minerals. Such minerals, like biotite, chlorite, and many hydromicas dissolve in small quantities in acids. Nevertheless, their exposure to acid treatment results in a selective elimination

of a proportion of the components from a wide surface zone. This causes a purified rim with a low refractive index to form around the grain, excluding the possibility of any further optical analysis of the given minerals.

Since acid processing of the materials turned out to be unsuitable in a number of cases, an attempt was undertaken to get rid of the carbonate material with the aid of electrodialysis.

2. Method of Operation

The electrodialytic method is described in the literature in detail. There are a great number of published works devoted to the application of electrodialysis in mineralogy [1-3]. Thus, a description of the method's principles in this study seems to be superfluous and we shall dwell only on matters directly connected with the solution of the problem at hand.

A standard Pauli electrodialyzer with a 300 cm^3 capacity chamber was used in the experiments. Platinum electrodes were utilized with cellophane serving for membrances. The tests were conducted at a voltage of about 300 volts and a current of up to 300 milliamperes. Electrodialysis with a continuous CO_2 flow (Figure 1) was utilized to accelerate the process of solution and transport of carbonate material. Carbon dioxide was supplied into the cathode chamber through a reducer from a container, with carbonic acid entering the central chamber by way of diffusion through the membrane. This scheme guaranteed a constancy of pH values in the cathode chamber and protected the cathode membrane from being clogged with carbonates. Shifting of the reaction in the central chamber proceeded rapidly enough, and the pH values of the investigated suspensions dropped from 8 or 9 to 4 or 4.5 in the course of 1-2 hours, remaining at this level until the end of the experiment. At such pH values and with excess carbonic acid a more readily soluble type of bicarbonate forms, and the whole process of carbonate-admixture dissolution is accelerated by a factor of three to four. A sharp increase in the system's conductivity permits the test to be conducted at the highest values of current densi
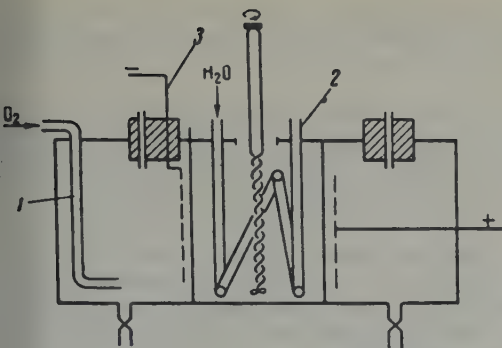

FIGURE 1. Diagram of the electrodialyzer

1 - carbon dioxide supply tube; 2 - cooler; 3 - electrode.

However, when power exceeds 10 volts, the installation begins to heat very rapidly and the use of a special cooler becomes necessary. The cooler utilized in our case consisted of a glass coil pipe fitted into the central chamber and connected with an ultrathermostat. Utilization of an ultrathermostat permitted the temperature in the chambers to be maintained at the required level.

It has been established in practice that in optimum test conditions up to 1 gm of calcite may be removed from the sample in 1 ampere-hour. This rate of carbonate extraction is not constant and depends on the temperature, availability in the rocks of other soluble acids, character of the absorbed complex, degree of the hydrolysis of silicates, and so on.

In the case of large quantities of mixtures charged into the electrodialyzer, and correspondingly large amounts of the extractable carbonate, the excess of carbonate is deposited on the cathode. This results in a sharp drop of the circuit conductivity and requires periodical cleaning of the cathode. To facilitate the cleaning operation, use was made of an immersible electrode, mounted on a stopper and introduced into the chamber through the charging hole at the top of the cathode chamber (Figure 1). This construction of the electrode assured its quick replacement, requiring no dismantling of the entire system. The portions of carbonates extracted in the acids combine with the accumulated quantities of catholyte, and may, as need arises, be used for analyses.

3. Description of Experiments

1) Selection of Optimum Operating Conditions. The rate of Ca (or Mg) extraction from the central chamber depends on many factors. Apart from the intensity of calcite (dolomite,

magnesite) dissolution, a very considerable role in this process is played also by the factors which determine the degree to which Ca (or Mg) ions participate in the transport of the charges to the cathode. If other cations (besides those of Ca or Mg in which we are interested) are present in the solution, they also participate in the transport of charges. The extent of their participation is proportional to their concentration, valence, and mobility.

In view of the abundance of variable active factors, their total influence on the variation in the rate of transfer of Ca ions cannot be estimated beforehand. Yet, the behavior of Ca(Mg) ions in aqueous media under different gas-flow and temperature conditions is of primary significance in the selection of corresponding equipment and conditions for electrodialysis. In order to select optimum conditions, we have carried out special experiments on electrodialysis of calcite, dolomite, and magnesite suspensions in utilizing CO_2 current, as well as separate tests on electrodialysis of carbonates at various temperatures.

Pure salts were used in these experiments. This excluded the participation of any other (save Ca^{++}, Mg^{++}, H^+) cations in the transfer of charges. Variation of the test temperature or the inflow of carbon dioxide in these cases produced an effect only on the rate of solution of the corresponding carbonaceous salt and the ratio of the "competing" H^+ and Ca^{++} or Mg^{++} cations in the solution.

The tables and curves reproduced below illustrate the variation in the speed with which the corresponding cations are transferred from the central chamber depending on the experimental conditions. Apart from the amounts of $CaCO_3$ and $MgCO_3$ extractable per unit of quantity of electricity, the recorded figures show the efficiency of power consumption in the electrodialyser under different conditions (see column: milligrams of material per watt-hour). These figures are almost entirely dependent on the solubility of salts in each case, and serve as an indirect indication of the extent to which the H^+ ions and those of a metal participate in charge transfer. Since the degree of dissociation of water in carbonic acid is negligible, the system's conductivity, when the sample is not charged into the central chamber, remains at a fairly low level, both in the case with distilled water and when the system is saturated with carbon dioxide.

Measurements have shown that the resistivity of the system without loading of the sample and without carbon dioxide current is almost constant, ranging from 30 to 35 thousand ohms over the 20° to 70° temperature range. At temperatures below 20° the system's resistivity begins to grow, reaching 40 thousand ohms at 10°.

Such indistinct variation of resistivity is attributable to the fact that a simultaneous rise in temperature and growth of the degree of water dissociation is accompanied by an appreciable reduction in the amount of the dissolved gases, and the total number of ions in the solution remains approximately at the same level.

Saturation of the system by CO_2 is reflected only at low temperatures, and the resistivity of the system increases from 14 to 20 thousand ohms with a rise in temperature from 10 to 20° On further increase in temperature, the system's resistivity remains at the same levels as in the cases not involving introduction of carbon dioxide. The presence of calcium and magnesium carbonates in the electrodialyzer

resistivity, but the cathode compartment loses $Ca(OH)_2$, and its resistivity becomes higher th: in the first case.

Measurements have shown the following dis- tribution of voltage drops in the chambers, wi: the distance between the electrodes and the membrances being 1 cm, and the length of the central chamber 6 cm (Table 1, in percent).

It may be seen from the table that in order to obtain the best possible effect and maximum efficiency in power consumption in the electro- lyzer the anode grid must be pressed onto the membrane, since most of the power is used in overcoming the resistance of anolyte. No con- tact whatsoever between the cathode and the

Table 1

Conditions	Cathode chamber	Central chamber	Anode chamber
With CO_2 current	10	17	73
Without CO_2 current	5	20	75

causes resistivity to drop sharply. At a tem- perature of 20° it drops 1500 to 2000 ohms. These figures hold both where the system is saturated with carbon dioxide as well as where carbonic acid is not being introduced. The ap- parent inconsistency may be explained by the different character of the solutions in the cham- bers of the electrodialyzer. Thus, in the cathode chamber, if CO_2 is not supplied, a con- siderable proportion of Ca fails to fall out in the form of carbonate salt, because the input of Ca ions turns out to be too fast and the cathode compartment fills with $Ca(OH)_2$ solution (the solubility of $Ca(OH)_2$ being far greater than that of $CaCO_3$). Consequently, when operations are conducted without a supply of CO_2, one link in the circuit (the cathode chamber) displays a far lower resistivity than when CO_2 is introduced. In the latter case, a certain quantity of carbon- ate in the central chamber turns into more readily soluble bicarbonate. This determines a certain reduction in the central chamber

membrane is admissible, because deposition of crystalline calcite on the cathode will cause the membrane to fuse with the cathode and result i cracking of the membrane.

Tabulated below are the rates of Ca and Mg migration under different experimental condi- tions. The duration of tests in all cases was the same, amounting to 6 hours (Table 2).

Voltage in all cases was maintained at the level of 300 volts, and the varying character of figures is attributable to the variations in the system's conductivity, the current strength, ar the amount of cations transferred.

As is evident from Table 2, the migration of calcium almost doubles in the presence of a CC current. Dissolution and migration of dolomite are also sharply accelerated, although it is Ca that is primarily removed. It seems that lowe: pH values are required for the mobilization of

Table 2

Mineral	Conditions	Total transfer of carbonates in milligrams		Transfer of substance in milligrams a·h	Transfer of substance in milligrams/wt·h
		$CaCO_3$	$MgCO_3$		
Calcite	—	361	—	634	2.12
	CO_2	623	—	1050	3.66
Dolomite	—	163	9	382	1.44
	CO_2	255	23	662	2.41
Magnezite	—	—	42	465	1.55
	CO_2	—	86	337	1.13

Mg. The conditions of our experiments were conducive to Mg hydrolysis and the formation of brucite or its basic salts.

In the experiment with magnesite, the CO_2 current was responsible for more than doubling the rate of Mg migration. But the strength of the current did not increase in proportion to the quantities of Mg removed, and the power output per milligram of substance has risen slightly. The smaller total amounts of extracted Mg (as compared with Ca), apparently, also depend on the hydrolysis of magnesite and the formation of less soluble salts. However, in almost all cases the inflow of carbon dioxide caused the process of carbonate extraction to proceed approximately twice as fast.

The temperature influence is also significant. In the case of magnesite dissolution, the best results were obtained at low temperatures. At 15° the amount of Mg extracted is almost twice that removed at 50°.

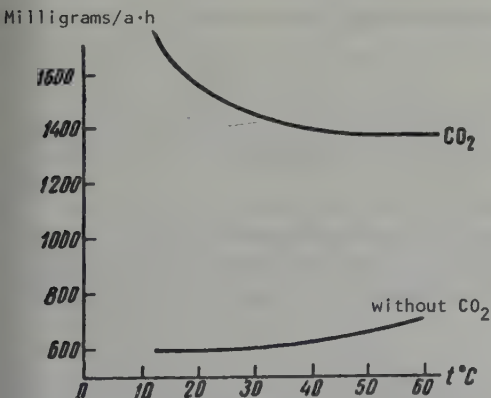The relationship for calcite turned out to be fairly complex. The curves (Figure 2) show a

FIGURE 2. Temperature curves of the rate of carbonate extraction (in milligrams/a·h)

definite tendency towards a slower unit transfer of $CaCO_3$ per 1 ampere-hour with rising temperature. Such a relationship is attributable to the fact that a rise in temperature reduces the solubility of CO_2 in water and, consequently, diminishes the influence of carbonic acid on the process of carbonate dissolution. Yet, an increase in temperature is not only reflected in the dissolved carbonic acid content, but also produces an effect on the rate of calcium dissolution and the formation of bicarbonates. The latter are in a direct, not inverse, relationship to temperature. The superposition of these phenomena complicates the pattern of dissolution and migration of carbonates. Consequently, 40 to 50° appears to be the optimum temperature of the experiment, for it is then that the quantity

of $CaCO_3$ removed per unit power consumption attains its highest absolute value (Figure 3).

In the latter case a repetition of the shape of the curves with and without CO_2 current is attributable to the fact that the system is not isolated from atmospheric CO_2.

A rise in temperature from 20 to 40° causes the transfer of Al and Fe from montmorillonite and chlorite to increase by a factor of 1-1/2 or 2. But the absolute values of these quantities are so insignificant that they fail to produce any effect on the character of the investigated minerals.

2) Removal of Calcite from a Mixture with Kaolinite. The initial mixture was prepared by blending 9 g of the subcolloidal fraction of kaolinite (from Turbovskoye deposits) with 1 g of pure calcite powder (ground iceland spar). The pH of the initial suspension was 7.85.

In the course of the experiment with continuous CO_2 current flowing into the cathode compartment, terminal voltage of 25 to 80 volts, and current strength of 80 milliamperes, an acid reaction with pH = 5.5 was maintained in the central chamber. A total of 1.2 ampere-hours was required to assure a complete
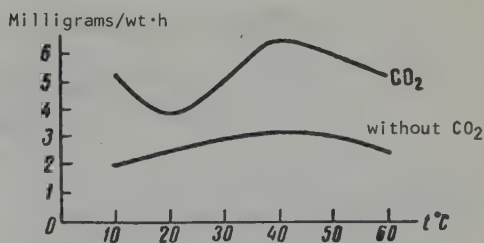
FIGURE 3. Temperature curves of the rate of carbonate extraction (in milligrams/wt·h)

removal of $CaCO_3$ from the mixture. A loss of 0.9% in weight of kaolinite was registered. The optical properties of kaolinite and its chemical composition remained unchanged (Table 3). Only a slight relative enrichment of the Si and Ti residue due to a small loss in other components was to be observed.

3) Removal of Calcite from a Mixture with Montmorillonite. The mixture was prepared in a manner similar to that described in the first case. A mixture of 9 g of the subcolloidal fraction of montmorillonite (gumbrin) and 1 g of calcite was treated in a three-chamber electro-dialyzer. Voltage was maintained at the level of 40 to 50 volts, the strength of the current being up to 80 milliamperes. The pH value of the initial suspension was 9.15. In the course of the experiment the pH values in the central

Table 3

Sample	SiO₂	TiO₂	Al₂O₃	Fe₂O₃	FeO	GaO	MgO	K₂O	Na₂O	H₂O+	H₂O	Total
Initial kaolinite:	44.64	0.79	38.18	0.81	0.13	0.80	0.46	0.34	0.56	12.20	1.31	100.22
Kaolinite After electrodialysis:	45.16	1.10	38.05	0.67	0.13	0.48	0.38	0.20	0.38	12.04	1.30	99.89

chamber were maintained at a level of 4 to 4.5. After purification the montmorillonite suspension showed a pH of 3.45. One ampere-hour was required for total extraction of $CaCO_3$ from the suspension. The optical properties of montmorillonite revealed an insignificantly small degree of change after treatment in the electro-dialyzer (Table 4).

Chemical analysis of the anode liquors showed that about 0.02% of SiO_2 was removed from the central chamber during the experiments. A 1.1% loss in weight of montmorillonite is attributable to the elimination of Al, Mg, Ca, K, Na. The total quantity of these components in oxide form transferred into the catholyte comprises about 0.9% and corresponds to the amount of

Table 4

Sample	γ	α
Initial montmorillonite:	1.516±0.002	1.498±0.002
Montmorillonite after electrodialysis:	1.519±0.002	1.498±0.002

The chemical composition remained also almost identical (Table 5, in percent). The loss

SiO_2 accumulated in the central chamber in the form of silica.[2]

Table 5

Sample	SiO₂ aм	SiO₂	TiO₂	Al₂O₃	Fe₂O₃	FeO	CaO	MgO	K₂O	Na₂O	H₂O+	H₂O−	CO₂	Total
Montmorillonite, initial:	7.20	49.88	0.33	14.99	2.98	0.13	2.48	3.74	0.10	0.56	5.49	11.21	1.32	100.41
Montmorillonite, after electrodialysis:	8.49	48.55	0.26	14.95	3.25	0.13	2.28	3.46	0.05	0.09	5.46	11.72	1.42	100.11

of Na in the residue is attributable to the removal of the absorbed complex. The content of amorphous silica increased owing to incomplete transfer of Si into the anode compartment.

[2] The high content of amorphous silica in the initial sample is due to the presence of volcanic-glass relicts The glass is partially crystallized with formation of β-christobalite detectable by X-ray analysis.

Analysis of the chemical composition and optical constants of montmorillonite indicates that the insignificant dissolution of montmorillonite in the process of electrodialysis occurs in molecular quantities and does not, consequently, affect the properties of the mineral. This conclusion si borne out by a comparison of thermograms of montmorillonite taken before and after electrodialysis (Figure 4).
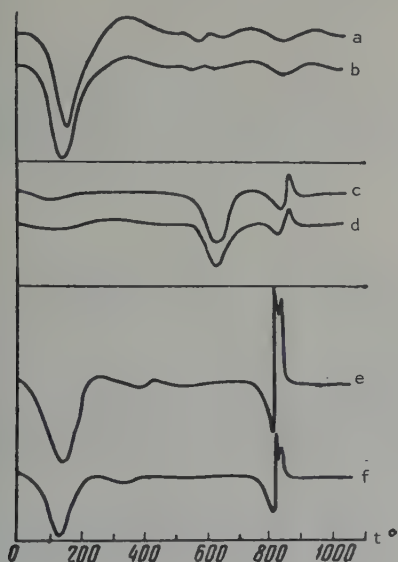
FIGURE 4. Thermograms of the investigated samples:

a - initial montmorillonite; b - montmorillonite after electrodialysis; c - initial chlorite; d - chlorite after electrodialysis; e - sepiolite, initial; f - sepiolite after electrodialysis.

4) Removal of Calcite from a Mixture with Sepiolite. The initial mixture was also prepared from 9 g of sepiolite (Akkerman deposits)

and 1 g of calcite. Sepiolite was taken in a fraction < 0.01. Electrodialysis was conducted with uninterrupted flow of CO_2 current into the cathode chamber, at a voltage of 40 to 60 volts and current strength of 100 milliamperes. A quantity of electricity equal to 0.9 ampere-hours was required for total removal of $CaCO_3$. The weight loss amounted to 1.43%. MgO, the total quantity of which in the catholyte is equal to 96 milligrams (1.05%), accounts for two-thirds of the weight loss. The amount of SiO_2 transferred into anolyte is about 9 milligrams (0.1%); excess of amorphous silica in the residue was 1.08%; SiO_2 absorbed on the anode membrane was 29 milligrams, or 0.32%. Thus, the total transfer of SiO_2 amounted to 1.5% and does not altogether correspond to the extracted quantity of Mg. Yet, the discrepancy is so negligible as to be commensurate with experimental error and is not reflected in the optical characteristic of the mineral (Table 6).

The optical characteristic is given in Table 7.

The character os thermograms also remained identical (Figure 4). With strict maintenance of the registered temperature pauses, only a slight drop in the intensity of the corresponding peaks in sepiolite after electrodialysis appeared (Figure 4).

5) Removal of Calcite from a Mixture with Chlorite. The initial mixture was prepared from 9 g of chlorite (pennine) and 1 g of calcite. The chlorite fraction measured < 0.01. As in the previous tests, electrodialysis was conducted with an uninterrupted flow of CO_2 current into the cathode chamber at a voltage of 100 volts and current strength of about 80 milliamperes. The quantity of electricity needed to assure complete elimination of $CaCO_3$ was 1.44 ampere-hours. The loss in weight of chlorite comprised 3.04%. The refractive index of chlorite platelets, measured at the base, remained unchanged. In both cases n = 1.596 = 0.02. The thermograms of the initial chlorite and the residue are identical (Figure 4). The chemical composition also remained the same (Table 8, in percent values).

Table 6

Mineral	SiO_2 amorphous	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O+	H_2O-	Total
Initial sepiolite	1.01	52.31	0.40	0.29	0.04	0.59	23.54	0.06	0.11	8.09	13.21	9965
Sepiolite after electrodialysis	2.09	50.89	0.58	0.41	0.04	0.59	23.98	0.05	0.14	7.75	13.14	9966

Table 7

Mineral	γ	α
Initial sepiolite:	1.512 ± 0.02	1.497 ± 0.02
Sepiolite after electrodialysis:	1.512 ± 0.02	1.494 ± 0.02

A parallel treatment of the chlorite-calcite mixture by 2% HCl without heating (before removal of $CaCO_3$) resulted in the solution of 7.95% chlorite.

times the resolution of the microscope. The re fractive index of the rim is 1.583 = 0.02, which distinguishes it considerably from the initial chlorite. The change in optical characteristics

Table 8

Mineral	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O+	H_2O-	Total
Initial chlorite:	28.32	0.39	21.01	2.90	3.85	0.76	30.30	0.03	0.17	11.39	0.59	99.71
Chlorite after electrodialysis:	28.26	0.72	19.75	3.07	3.96	0.67	29.65	0.06	0.11	11.72	1.35	99.32
Chlorite after treatment by 2% HCl:	28.48	0.62	20.95	2.63	3.95	0.67	29.66	0.03	0.13	11.05	1.45	99.62

The ratio of the components in the hydro-chloric extract of chlorite differs essentially from their ratio in the initial sample (Table 9, in percent).

of the surface zone of the mineral bears witness to the selective dissolution and the predominance of Al, Fe, and Mg migration precisely from the surface zones of mineral grains. The thickness

Table 9

Sample	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	K_2O	Total
Hydrochloric extract of chlorite:	19.58	27.92	7.37	4.09	40.75	0.25	99.96

Migration of predominantly Al, Fe, Mg, and K was observed. However, this was not reflected sufficiently in the total composition of chlorite in the residual product. The reason for this apparent inconsistency is concealed in the fact that the greatest change resulting from acid treatment was registered in the surface of chlorite grains. Microscopic examination of the preparations made it possible to discern a distinct purified rim along the perimeter of the chlorite grains. Its thickness exceeded many

of the altered film, even though sufficient for optical observation, is still many times inferior to that of the grains and, therefore may not seriously affect the total chemical composition of residual chlorite.

6) Solution of Calcitic Cement in Sandstone with Apatite. A 10 g sample of natural cal-careous sandstone was taken for this experiment from the section of Lower Cretaceous deposits in Yakutiya (Vilyuy River). The

granulometric composition of the sandstone is given in Table 10 (in percent values).

The bulk of the heavy fraction of the sandstone is to be found in the 0. 1 to 0. 05 mm size interval which also contains the overwhelming proportion of apatite grains. In the process of primary screening fragments measuring < 0. 25 mm were sifted out. This fraction consisted of fragmental grains contaminated with carbonaceous material, aggregates of fine grains cemented by calcite, and fragments of calcite. The total amount of calcite in the sample comprised 2 g. Electrodialysis was conducted with a continuous flow of CO_2 current into the cathode chamber. Purification of the sample required 1. 2 ampere-hours, or 0. 6 ampere-hours per 1 g of $CaCO_3$.

sufficient quantity of zeolite 60 g of rock were taken. A total of 15 ampere-hours (0. 68 ampere-hours per 1 g $CaCO_3$) was required for a complete removal of calcium carbonate (22 g) and separation of the fragmentary grains from those of zeolite. Subsequent separation of zeolites, carried out with the aid of a centrifuge, made it possible to accumulate up to 3 g of the pure zeolitic fraction.

CONCLUSIONS

1. The completed experimental operations proved that application of electrodialysis for removal of carbonate admixtures and cement from rocks yields satisfactory results. In all cases the necessary mineral components

Table 10

Fractions of mechanical composition						Insoluble residue
>0.5 0.37	0.5—0.25 22.11	0.25—0.1 49.35	0.1—0,05 7.00	0.05—0.01 7.09	<0.01 11.08	80

After disaggregation and total elimination of calcitic cement a heavy fraction was separated in the intervals 0. 25 to 0. 1 and 0. 1 to 0. 01 mm. The apatite grains turned out to be quite fresh in both fractions. A chemical analysis of the anode liquor showed only the presence of traces of P_2O_5.

7) Solution of Calcitic Cement in Sandstone with Zeolites. In this experiment use was also made of a sample of calcareous sandstone taken from the section of Lower Cretaceous deposits in Yakutiya (Vilyuy River). The grains of zeolites (epistilbite) were observable in the sections in the form of epigenetic new formations measuring less than 0. 1 mm. Carbonaceous cement in the sandstone displayed a coarse crystalline texture and was found to have corroded both the fragmental grains of feldspar and quartz as well as those of zeolites. The contact of calcite with zeolite along the intricately dissected surface assured an exceptionally firm cohesion of the calcite-zeolite aggregates, which could not be separated even by application of ultrasonic waves.

First to be subjected to electrodialysis with CO_2 current was the pre-ground fraction of the rock < 0. 25 mm which, as in the preceding case, contained fragmental grains, aggregates cemented by calcite, and fragments of calcite. The amount of carbonate admixtures in the sample comprised 37%. To accumulate a

soluble in acids appeared to be almost totally unadulterated by dissolution processes as a result of electrodialysis with carbon-dioxide current. The losses in both the known silicates and apatite permit this method to be used without fear of dissolving any appreciable quantities of argillaceous minerals, zeolites, and apatite, and to accumulate the disaggregated fractions for subsequent study or isolation of pure varieties.

Exposure of chlorite, montmorillonite, sepiolite, and kaolinite to acid treatment resulted in a differentiated solution of these minerals. In all cases, the dependence of solubility on the initial size of the fraction was observed. Most conspicuously, this relationship was manifested in the process of sepiolite solution (Table 11).

The size of the initial fraction seriously affects the rate of transfer of carbonates. In the experiments referred to above a fraction of calcite < 0. 01 mm was used in all cases. Such coarseness of the initial fractions is most probable and effective in work with argillaceous and argillaceous-carbonaceous rocks.

In disaggregation of arenaceous rocks, the size of initial fractions is determined by the coarseness of the fragmentary material.

2. In experiments on purification of mineral

Table 11

Minerals	Solution of the substance in 2% HC1 (in percent values)			Losses after electrodialysis (in percent)
	< 0,1	< 0,01	< 0,001	
Kaolinite		to 2	to 3 *	0.9
Montmorillonite		to 6	to 10 *	1.1
Chlorite		to 8 *	to 12	3.04
Sepiolite	to 12	to 20 *	to 40	1.43

*Fractions taken for electrodialysis.

mixtures, and in a number of special tests to define the speed of dissolution of carbonates, optimum conditions were established under which the greatest effect may be achieved in operations designed to purify mixtures from carbonaceous materials.

In all cases, a flow of CO_2 current into the cathodic chamber sharply accelerates the process of Ca and Mg migration.

The optimum temperature for extraction of calcitic admixtures and calcitic cement is 40 to 50°. In the case of dolomitic or magnesitic admixtures, the optimum temperature is lower (10 to 15°).

In cases involving argillaceous-carbonaceous mixtures the quantity of energy (0.9 to 1.2 ampere-hours) required for the removal of 1 g of calcite is 1.5 to 2 times greater than processes involving calcareous sandstones (0.6 to 0.7 ampere-hours). This difference is attributable to the presence in clay of a greater proportion of soluble components, which to a considerable extent increase the conductivity of the system and constitute a sort of an "internal shunt". Moreover, continuous and energetic agitation of the mixture with carbonate and quartz grains leads to a considerable fragementation of calcite and penetration of larger quantities of finely-dispersed carbonaceous material into the suspension.

3) The design of the chamber also exerts an influence on the speed of the removal of carbonate admixtures from the rock. In assembling the electrodialyzer, it is important to be sure that the anode grid is pressed against the membrane, since the anode chamber accounts for the maximum proportion of voltage drops. A reservation should be made here to the effect that whenever the sample becomes clogged with sulfates and halides, the anode must be removed from the membrane, since atomic chlorine and hydrochloric, or sulfuric acid forming on it have a destructive effect on the membrane. After the removal of the anode from the membrane, the latter becomes subject to the action of already diluted acids which do not cause rapid deterioration of cellophane, parchment, or colloidal film.

The cathode grid must always be slightly removed from the membrane, since the formation of carbonate salts on the cathode may cause the membrane to fuse with it and be damaged by cracking.

For purposes of more convenient periodical cathode cleaning it is advisable to utilize the immersible type of electrode, which may be removed without dismantling the entire system. The high conductivity of the system resulting after the loading of carbonate samples into the central chamber, permits the tests to be conducted at current-strength values of 300 to 400 milliamperes and higher, without increasing the voltage above 200-300 volts. Under such conditions, the use of coolers becomes mandatory since the unit rapidly heats to the boiling point.

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MICROLENS SUPPORT (MD-1 SYSTEM)[3]

by

V. P. Maslov

In many cases involving paleontologic and other types of investigation it becomes necessary to examine an object under the microscope, particularly the binocular microscope, from all sides. In particular, such contingencies may arise when studying and photographing the spore remains of characeae whereby a description of the apex, the base, and the side-view is mandatory. The same applies to the foraminifera and other fossils isolated from rocks. In these cases, it becomes necessary to fasten the investigated object onto a slide for each required position. Sometimes this proves to be difficult, particularly, when the lower part of the object is tapered.

The proposed support, a description of which will be found below, is designed to facilitate this task. The first variant was made of aluminum by T. V. Dalmatov.

The support consists of cylindrical bracket 1, provided with three set screws, and the object-carrying pin 2 which may be pushed freely through the upper part of the bracket.

part of the bracket and braced in it by means of set screw HC. The upper part of the bracket b is a massive cylinder rotating on the lower part, and has a cylindrical through-hole (passing through the center) corresponding to the diameter O of the pin. This hole penetrates the entire cylinder in a horizontal direction. The set screw LSS, located at the top in the center of the bracket, passes all the way through to the pin and serves to clamp it in the required position. The lateral set screw LSS, situated on the side of the bracket under the pin, is used to fix the upper rotating part of the bracket in the desired position. This lateral screw (in accordance with T. V. Dalmatov's suggestion) also serves to hold the upper part of the bracket in passing through a slit on its side. In pressing the edges of the slit onto the inner cylinder of the immobile lower part of the bracket, the screw fixes the upper cylinder at a desired point along its limited arc of rotation (30 to 40°).

Pin 2 is a cylinder 10 to 15 cm long, 5 mm in diameter. It has a conically tapered end provided with a facet F, 0.5 mm in diameter. The object to be examined is fastened to this facet.

In order to use the support, the bracket must be clamped to the edge of the microscope table by means of the lower screw to assure that the pin reaches the microscope axis. Thereafter,
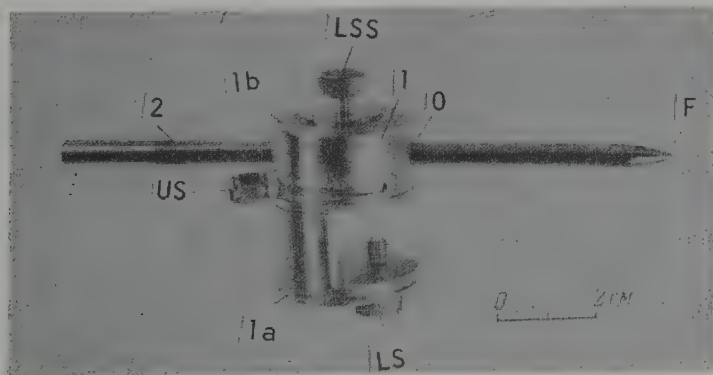
Picture of the holder for microscopic objects

1 - bracket, attachable to the edge of the microscope table by its lower section (1a); 1b - the upper turning part of the bracket; 2 - pin with object-carrying facet F; LS - lower, US - upper, LSS - lateral set screws; O - bracket through-hole for the pin. The scale is in centimeters.

The lower part of the bracket (1a) is rigidly fastened to the table of the microscope or binocular microscope. The edge of the microscope table is inserted into the recess in the lower

the pin is withdrawn from the bracket and the microscopic object is glued onto its end with a solution of sugar. Then the forward section of the pin together with the object is pushed through the hole in the bracket and moved up to the axis of the lens. First, the necessary adjustment is made along the axis of the bracket. When the bracket is fixed into position, the object may be

set in the visual field as required for observa-
tion by pushing out or pulling in the pin, and
turning it about its own axis. The pin is then
properly secured by the upper set screw.

A relatively thick pin was selected for the
following reasons. When a thin pin is being
thrust through the bracket hole, there is always
the risk that in brushing against the walls of the
hole the object may be separated from the pin.
Experiments were carried out with a pin 2 mm
thick, but it was found that work with it was dif-
ficult. In using a thick pin, it is important to
exercise great care in pushing the pin along the
hole axis until the entire tapered end enters the
hole to prevent a possible loss of the object.

This type of support is convenient and simple
in use; it assures rapid operation and reliable
fixation of the object in the required position.
Of course, in each separate case the investi-
gator must fasten the object to the end of the
pin in an appropriate way. Thus, elongated
objects should be set laterally to permit ob-
servation from the sides and both ends.

The proposed support is simple to fabricate
and may be made of aluminum or plastic mate-
rial.

For holding objects smaller than 0. 5 mm in
diameter, the pin's cone must be tapered sharp
and the facet supporing the object should be
made correspondingly smaller. For objects
measuring a few tens of microns use could be
made of thin-pointed needles which could be set
into a hole drilled in the tip of the pin. But in
this case it is advisable to glue the object onto
a needle already set in position and then push
the needle-carrying pin through the bracket.

The dimensions of the bracket are not speci-
fied here, since this is a matter of no funda-
mental significance. They may be varied. In
its first variant the bracket cylinder was 2. 9 cm
in diameter, its height was 3. 7 cm, the recess
for the microscope table 1. 7 cm. For micro-
scopes with thicker tables the recess must be
wider and the over-all height of the bracket
correspondingly larger.

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ELECTIONS OF AN ACADEMICIAN OF THE DIVISION
OF GEOLOGICAL AND GEOGRAPHICAL SCIENCES
OF THE U.S.S.R. ACADEMY OF SCIENCES IN 1960 [1]

On June 10, 1960, the General Assembly of the U.S.S.R. Academy of Sciences elected its Associate-Member, Yevgeniy Konstantinovich Fedorov, Member of the Academy of Sciences, Department of Applied Geophysics.

He is well known to the Soviet public as one of the four courageous explorers stationed on the first drifting base "North Pole 1" in 1937. During this drift, Yevgeniy Konstantinovich conducted very fruitful investigations in the field of magnetism, gravity determination, and clarification of other physical phenomena in the Arctic Ocean area. On the basis of the information collected in these studies he published a number of important scientific generalizations, and was elected Associate Member of the U.S.S.R. Academy of Science, Department of Geography, in 1939.

[1]Vybory akademika po Otdeleniyu geologo-geografi-cheskikh nauk Akad. Nauk S.S.S.R. v 1960 g.

However, Ye. K. Fedorov's scientific interests were not confined only to the problems of geography. His published studies, more than forty titles, are mostly devoted to questions of geophysics, atmospheric physics, and meteorology. He has proposed a personally developed method for the study of air ionization which has now won universal recognition among Soviet scientists.

At the present time, Yevgeniy Konstantinovich is successfully working on the problem of man's active influence on weather and climate.

The broad erudition and the wide scope of scientific interests of the newly elected Academician, Yevgeniy Konstantinovich Fedorov, justify the hope that in his person this new addition to the Division's staff will contribute to the development of the field of activities of the Division of Geological and Geophysical Sciences which up to now was in all fairness considered inadequate, namely, the field of geophysical methods of investigation.

REVIEWS AND DISCUSSIONS

ON THE SIDERITES OF BAKAL[1, 2]

by

Z. M. Starostina

The contents of the article On the Location of Bakalian Siderites in the Enclosing Rocks, by N. V. Grinshteyn, Yu. A. Davydenko, O. P. Sergeyev, and V. A. Timashov, may be broken down into two parts. The first part is confined to accusations leveled at me for insufficient and unauthentic references to the materials utilized, for distortions of certain descriptions, appropriation of materials, and so on. The second part contains remarks on the substance of my paper. These remarks refer to matters of principle and deserve greater attention. Hence, it is proper to discuss them first.

According to the data of these authors, "many authentically established and important geologic features of the Bakal region" are ignored by me ([3], p. 4), namely: the pre-Zigalginian erosion, 2) the sequence uniformity of the Bakalian series; 3) the zonal replacement from south to north of siderite by dolomite, and of dolomite by limestone; 4) the coincidence of the overwhelming proportion of iron-ore deposits in Bakal with the stratigraphic nonconformity between the Bakalian series and the overlying quartzites, and so on.

We shall venture to analyze these remarks.

1. A reference to the discordant bedding of the Zigalginian quartzite on the underlying deposits and to the presence of a deep-seated pre-Zigalginian erosion was made perfectly clear on page 54 of my paper and this fact was repeatedly mentioned in other places in the text (pp. 43, 50, 52). Moreover, it is stated that as a result of this erosion a number of the beds

of the Bakalian series were truncated. However there was no "deposition from the sequence of a greater part of the beds of the Bakalian series", as stated by my opponents ([3], p. 4). These are fundamentally different things. Since the phenomenon of ore formation is not related by me, as it is by Yu. A. Davydenko [4, 5], to the surface of the unconformity between the Zigalginian and Bakalian series, I do not deem it necessary to dwell on this matter in greater detail.

2. The question concerning the uniformity of the Bakalian series is by no means passed over in silence. On the contrary, an argument is made throughout my entire work in favor of a gradual change of the Bakalian series, from the north and northwest to the south and southwest, manifesting a diminution of its carbonaceous character and the increasing significance of the terrigenous members. Moreover, it is not clear what the authors of the article have in mind when they speak of a disagreement between these data and the conclusions drawn by the preceding investigators, M. I. Garan' in particular. M. I. Garan' emphasizes the natural pinching out of the carbonaceous members of the Bakalian series as they extend westwards, and their replacement by phyllitic slate [2].

The transformation and tapering out of the Berezovian formation from the northeast in the southwesterly direction is proven by a number of borehole logs. According to A. Ye. Malakhov's data [8], the Berezovian formation west of the Ob"yedinennyy and Imeni Lenina mines, where its thickness is estimated at no less than 160 m, is made up mainly of dense light-gray, occasionally almost white, limestone and dolomite. Slightly to the south, north of the Novobakal'skoye deposits, the same beds are composed of light-gray, solid, fine-grained dolomite, which sometimes displays a "wormy" texture (lenses and intricate irregular inclusions of fine-grained carbonate in the midst of clayey material). The logs of boreholes 1756 and 1757 show that the thickness of these beds does not exceed 70 to 80 m.

Within the limits of the Novobakal'skoye

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[1]O Bakal'skikh sideritakh.
[2]With reference to the article by N.V. Grinshteyn, Yu.A. Davydenko, O.P. Sergeyev, and V.A. Timeskov, see the News of the U.S.S.R. Academy of Sciences Geological Series, No. 7, 1960.

deposits the Berezovian beds are represented by limonite changing into siderite, which first becomes somewhat thicker towards the south-east, and then gradually begins to thin out until it totally disappears.

In the more southern sections (3-7) the Bere-zovian beds are represented by fine-grained siderite, which in places is lamellar and banded, with alternating gray siderite, dark argillaceous dolomite, carbonaceous-shaly, silty-pelitic material, and secondary dolomite (holes 1657, 1014, 1663, 1664, 1016, 1017, etc.). "Wormy" texture is also occasionally observable.

Revealed in the logs of some holes (1013) were frequent layers of rhythmically-laminated, coaly, carbonaceous shale. A layer of black argillaceous magnesite was detected in examin-ing the hole 1657 core corresponding to the in-terval between 372.75 and 777 m. The total thickness of these rocks varies, but on the average it is estimated at 50 to 60 m. Still farther south, in the region of Imeni OGPU mine, the Berezovian formation in borehole 1681 at-tains only 15 m in thickness, and is represented by laminated clayey siderite, which in individual layers displays a "wormy" texture, and is mas-sive in the lower part.

Southeast of this borehole the siderite is re-placed by dolomite. The latter, in turn, change into dolomites interstratified with limestone, 25 to 27 m thick (borehole 1648). It is difficult to understand how it is possible under these circumstances to deny the fact that the car-bonaceous rocks of the Berezovian formation are enriched by terrigenous material in the south and that the formation itself wedges out naturally.

The assertion of the authors that within the bounds of this region "a change of entire car-bonaceous beds, or of considerable parts of them, into argillaceous formations is non-existant" ([3], p. 7) stands in contradiction to their own observations, and bears witness to the fact that they simply refuse to see this phenomenon. For example, they do not deny that the Berezovian formation pinches out in the southerly direction. But they strive to ex-plain this by an alleged and totally unsubstanti-ated angular unconformity between the Berezo-vian formation and the Irkuskanian schist not recorded by anybody, not excluding the mem-bers of the Bakal geological survey group, either in print, or in handwritten reports [3]. In reality there is no such angular unconformity. Furthermore, in pointing out the considerable variations in thickness of the Lower Bakalian member, in particular, to its sharp reduction at Ivanovskoye and Aleksandrovskoye deposits, as well as in the northern part of the Irkuskan Central quarry" [3], i. e., percisely along the eastern fringe of the Bakal ore field, the authors relate this phenomenon to a stratigraphic

discordance in the foundation of the incumbent bed [3], the existence of which has neither been proved here or in any other place.

There naturally arises a question, to what phenomena do my opponents relate the forma-tion of these angular and stratigraphic uncon-formities within the Bakalian series which, in their opinion, is characterized by exceptional uniformity?

In his 1958 study, in characterizing the sec-tion of the upper part of the Bakalian series in Bulandikha Mountain, Yu. A. Davydenko writes that "a certain increase in the amount of ter-rigenous material in the carbonaceous beds in the western and southern directions is evident". Thus, the carbonaceous sub-member bg^2 in Obyedinennoye deposits displays a larger number of thin (fractions of one meter) slate layers than in other mines, whereas the thickness of the more massive layers bg^{2a} and bg^{2B} is somewhat augmented. The sections of northern deposits (Figures 1 and 3) reveal the absence of the sand-stone layer q bg^2 which is recorded in the Ob-yedinennyy and Bulandikhinskiy mines, and so on" ([5], p. 69).

Furthermore, the same author, in comparing the sections of this formation in Ob"yedinennyy and Zapadnyy mines ([5], Figure 9), clearly shows the increasing thickness of the sand-stone and a thinning of the carbonaceous beds from west to east. In paragraph 12 of the same paper he comes to the conclusion that ". . . the thickness and the rocks composing the Shuyda and Irkuskan sections must closely resemble those in Bulandikha Mountain (paragraph 2, [10]). With respect to the former (particularly in the case of Shuyda) one must, however, bear in mind a possible increase in the number and thickness of slate layers in carbonaceous beds (paragraph 2), a certain thinning of the latter, and the pinching out of the carbonaceous layers" ([5], pp. 86-87). The above data are borrowed from the work of one of the authors of the criti-cal review. They contradict the assertions of this very author about the uniformity of the Bakalian series ection.

The A-B section appended to the explanatory note prepared by O. P. Sergeyev and L. P. Malyuga in 1958 clearly shows a one-and-one-half times reduction in thickness of the middle carbonaceous sub-member of the Upper Bakalian member Bak_2^{5B} from the northwest to south-east, from Bulandikha Mountain to the Vosto-chnoye deposits.

A reference to the diminishing thickness of the Lower Bakalian member in the west-east direction is made by A. Ye. Malakhov. He states: "The thickness of the rocks of the Lower Bakalian formation is variable: in the western part, in the area covered by the Imeni OGPU mines, it attains 90 to 120 m, while in the

eastern part it drops to 25 or 30 m; at Irkuskan the average thickness is equal to 50 or 60 m" ([8], p. 64).

From the above stated it is perfectly obvious that the facies change of the Bakalian series does not occur only in the easterly direction, as noted by M. I. Garan', but also in the southern and southeastern directions. This change is manifested in a gradual replacement of the carbonaceous rocks by terrigenous clastic formations. There exists no angular or startigraphic unconformity whatever between the individual members of the Bakalian suite.

My opponents deny the existence of a coincidence between the iron ores and the slates in the southern part of the Obyedinennoye deposits, and regard the assumption as to the propensity of the argillaceous facies to carry chalybite ores in the conditions prevailing in Bakal as totally groundless.

The diminishing thickness of the ore-bearing carbonaceous formation Bak_{10} from north to south at the Ob''yedinennoye deposits as noted by me, is well expressed in the profile attached to my work ([12], Figure 8). It may be seen therein, that in borehole 306-a the thickness of the dolomites which underlie and cover the ore is very small. In borehole 332, located in the same cross-section as hole 306-a, though slightly to the west, they are not to be found at all in the hanging wall of the deposit, and are preserved only in the form of a minor layer in the lower part of the ore shoot. Further to the south, in the region of the Yuzhnaya shaft, the upper section of the deposit is truncated by the Zigalginian quartzite. Its lower boundary is constituted by schists, whereas dolomites are totally absent. The same relationships may be observed also in the longitundinal geologic section across the Obyedinennoye deposit prepared by the Bakal geologic survey party (V. K. Golovchenko, N. V. Grinshteyn, A. I. Usenko, 1953). Quite clearly shown here is the passage from northeast to southwest of limestone and dolomite of the Upper Bakalian formation into carbonaceous shale, and then into siderite (first orebody) supported and supperposed by argillaceous slate of the Middle Bakalian and Bulandikhan formations. It is on the basis of this relationship that one feels justified in stating that in this section of the deposit slates constitute the enclosing rocks for the brown hematite of the Bak_{10} horizon. Similar relationships are to be recorded for the horizon Bak_4 along the southeastern slope of the Irkuskan ridge. Here, according to the survey of the Scientific-Research Council of the Sverdlovsk Mining Institute conducted by V. A. Knyazev and Yu. S. Solovyev under the leadership of A. Ye. Malakhov (1945-1949), the orebody of the Bol'shoy Ivanovskiy mine serves as an example of a "mineralization of the stratified type". It represents an interbedding of thin and thicker

layers of ore with argillaceous, sandy argillaceous, and argillo-arenaceous slates, as well as with thin intercalcations of quartzose schist.

These data are particularly interesting in connection with the assertions made by my opponents concerning the coincidence of the deposits in Krepkaya and Okhryanaya pits with the dolomite of the Upper Bakalian formation, and with the statement made by Yu. A. Davydenko to the effect that the Novoaleksandrovskiye deposit are associated with schists [5]. All these deposits are located southeast of the Irkuskan ridge. They replace one another along the strike of the rocks from northeast to southwest. They are, thus, stratigraphically related to the Lowe Bakalian formation and are, apparently, located in the zone where its carbonaceous facies chang into a terrigenous clastic facies.

Considerable deposits of sideritic ores are well known among the argillo-arenaceous formations of the Zigazino-Komarovskaya and Avzyanskaya strata in Katav-Ivanovskiy, Zigazino-Komarovskiy, Avzyanskiy, Tirlyanskiy and Uchalinskiy regions, in the Urenginskaya series in the Zlatoustovskiy region and, finally, in the Yushinskaya series of the Yaman Tau ridge which constitutes a terrigenous clasti facies of the Bakalian series. It is, therefore, absolutely unclear why this possibility should be excluded with respect to the Bakalian series of the Bakal region.

3. The regular replacement of siderite by dolomite, and then by limestone within each member becomes apparent in the diagrams prepared by me on the basis of the borehole logs of the borings made by the Bakal geologic survey party, as is duly indicated in the introduction on page 40. The conclusion to which I came in analyzing these diagrams is fundamentally different from that of my oponents who repeat the already previously published views held by Yu. A. Davydenko [4, 5]. His view point is described in my article [12] on page 56. The displacement which he has observed in the Bulandikhinskiy mine of the horizon b_8^2 siderite first by dolomite, and then by limestone, from south to north, Yu. A. Davydenko [5] attributes to a selective metasomatic process. The boundaries between the indicated lithologic elements he is apt to consider as intersecting contacts. Yu. A. Davydenko believes that "the metasomatic character of the dolomites and their epigenetic origin with respect to the Bakalian series is, thereby, sufficiently evident" ([5], p. 78). O. P. Sergeyev's standpoint is outlined in his article of 1959, where he states: "The development of ore deposits was always accompanied by dolomitization of the enclosing limestone" (p. 24). In my work, while subscribing to the hypothesis concerning the primary sedimentary origin of the Bakal dolomite and siderite proposed by D. V. Nalivkin [9] and supported and developed by N. A. Ushakov [13],

A. Ye. Malakhov [6-8] and other authors, I am only striving to show the facies significance of the observable zonal replacement of the siderite by dolomite, and then by limestone, which in this case is characteristic of the marginal sections of the carbonaceous formations, of the zone of their gradation into a terrigenous clastic facies. Nowhere have I stated that I was the first to determine the existence of the indicated regularity. The view that I have expressed in the matter under no circumstances could be construed as being borrowed from any of the earlier investigators, and least of all, from Yu. A. Davydenko.

4. In correlating the distribution of ore manifestations with the general transformation of the Bakalian series, I come to the conclusion that "... the general trend of the entire mineralized zone as a whole, which corresponds to the region of transition of the carbonaceous facies into the terrigenous clastic facies, is northwesterly. At the same time the richest siderite-bearing facies are oriented in the latitudinal direction which is, apparently, attributable to the tectonic development of the Uralian foredeep in the zone where it abuts on the Ufa Plateau" ([12], p. 58). These conclusions have nothing in common with Yu. A. Davydenko's statements allegedly borrowed from him. It is stated in this author's work [5] that the east-northeastern (almost latitudinal) direction shows lines of total erosion of the individual members in the Bakalian series (i. e., lines of abutment of the lower horizon boundary with the Zigalginian series). Insofar as Yu. A. Davydenko associates the formation of siderites with the influence of intrusions, with the effect of parting in rocks, and with the protective role played by the Zigalginian quartzites (1956, 1958), the location of the iron-ore deposits, which, in his opinion, do not occupy any definite stratigraphic position, is, thus, subordinated to the latitudinal orientation of "the points of egress of carbonaceous beds of the Bakalina strata under the surface of the pre-Zigalginian unconformity" ([3], p. 3).

The fundamental divergence of the views expressed is so considerable, that the statement to the effect that I have borrowed the conclusion concerning the latitudinal trend of the richest siderite-bearing facies from the positions developed by Yu. A. Davydenko appears to be strange, to say the least.

Further, I consider as false any accusation that I have borrowed official and published materials without due recognition. On the very first page of my article I speak of the wide use made in my article of the diagrams, reports, and log records of the Bakal geologic survey group and the Administration of the Bakal Mining District. On the second page, with a corresponding reference, I state that, so far, the scheme developed by M. I. Garan' still serves

as the basis for the study of the Bakal deposits, and provide a concise review of this scheme. Further on, I indicate that by putting in deep boreholes, the Bakal geologic survey party has revealed new orebodies and was able to describe the section of the upper part of the Bakalian series with considerably greater precision. In outlining briefly these data and recognizing their merit, I emphasize that "such stratigraphic subdivision and comparison appear to be very convincing; they are, therefore, adopted by us in our further discussion of the stratigraphy, though with certain corrections in the designation of the members and with a change in the indexing system" ([12], p. 41). These member designations are given in a table in the column bearing the name of Z. M. Starostina.

From the aforesaid it becomes patently clear that there was no intention whatsoever on my part to take credit for the achievements of M. I. Garan' and the Bakal geologic survey party in the differentiation of the Bakalian strata. I have not visited the Bakal deposits since September 1957. I am, therefore, unfamiliar with the cores, which, according to the statement of the authors, were submitted by Yu. A. Davydenko and O. P. Sergeyev to the Scientific and Technical Conference dedicated to the Bicentenial of the Bakal mines in October 1957, and the description of which has not been published. Nor am I familiar with the charts of potential ore reserves which, persuant to the reports of the authors, are being prepared by the Bakal geological survey group since 1957. I have accepted the pattern of stratigraphic differentiation of the upper sections of the Bakalian series as a result of the work of the entire Bakal geological survey group, in conformity with the reference made in Yu. P. Yurilin's and Yu. P. Yurilin's and Yu. Ya. Rinkus' report (1958). I have, therefore, failed to recognize the authorship of O. P. Sergeyev in my footnote. If this is a misunderstanding, and O. P. Sergeyev is the author of the new scheme of classification, then I accept the reproach and will duly take it into account in the future.

The pattern of classification of the upper members of the Bakalian series developed by Yu. A. Davydenko (1958) was intentionally not utilized in the article, since it was prepared for Bulandikha Mountain and is inaccurate compared with the sections of Shuyda and Irkuskan. Moreover, in this comparison, Yu. A. Davydenko, while using M. I. Garan's designations for the members, correlates stratigraphically different complexes. This makes both the utilization of the scheme itself, and the application of the indexes to the entire area as a whole, difficult.

There is, indeed, no reference in my work as to the coincidence of the indexes proposed by me with those which appear in the lower part of Yu. A. Davydenko's core log [5] and in the core log of the Bakal geological survey group of 1954.

This is a fair reproach. The instability of the index system adopted to the Bakal Mining District may serve as a justification thereof. In a number of more recent handwritten and graphic materials of the B. G. S. G. , a system of indexing was adopted with a two-member division of the Bakalian series (Bak$_1$ and Bak$_2$[1, 2, 3]).

In the conclusion of their article, N. V. Grinshteyn, Yu. A. Davydenko, O. P. Sergeyev, and V. A. Timeskov, say that my prognoses exclude "from the sphere of prospecting, the area located in the Irkuskan-Buladikha syncline north of the zone of development of the stromatolithic and Lower Cakalian beds, although it is precisely here that the thick carbonaceous stratum (Bak$_8$) which is ore-bearing within the confines of the Shikhanskoye deposits passes" ([3], p. 10).

The following is stated in my paper with this respect: "In considering the latitudinal trends of the more enriched siderite-bearing facies, particular attention should be paid to the tracing of the siderite along the strike in the magnesite-bearing formation of dolomite and the stromatolithic stratum within the bounds of the Irkuskan-Bulandikha syncline". And somewhat further: "The areas to the north of these zones are, it seems, less promising and only small lenticular deposits may be encountered here. But to the south or southeast, tabular limonite orebodies may possibly be found in the zones of development of argillaceous facies" ([12], p. 58). Only two members are thus discussed: the magnesite-bearing Bak$_4$ and the stromatolithic Bak$_6$. The drilling data pertaining to the behavior of the higher carbonaceous formation Bak$_8$ were very scant by the time this article was written. The report of my opponents concerning the metalliferousness of this stratum within the confines of Shikhanskoye deposit not only fails to refute my earlier conclusions, but, on the contrary this permits them to be extended also over this carbonaceous formations, the high sideritic-ore content of which is covered by the same "zone". The northern boundary of this zone for this member will be, apparently, close to that of the stromatolith member ([12], Figure 6), as this is proved by the logs of boreholes 1762, 1788, 1803, and 511. The southern limit of the Bak$_8$ horizon is the boundary of the pre-Zigalginian erosion.

Lack of space prevents me from dwelling in greater detail on the minor comments. Let it be just mentioned here that in the comparison made in my work in Table 1, M. I. Garan's section was concerned only with respect to Shuyda and Irkuskan, and it was so stated. However, in this case the word "Buladikhan" was erroneously printed in the last left-hand column of the table somewhat higher. The Buldikhan formation here refers only to the fourth slate member Bak$_7$.

The rare limonite ore deposits in the Mesozoic erosion crust mentioned in the critical article have no bearing on the topic of my paper.

Furthermore, the authors question the data given by me with regard to the Lower Bakalian formation, stating that its thickness is constant and nowhere does it exceed 120 m. Nevertheless, according to prospecting profile 7 prepared by the Bakal geological survey party (V. Kh. Golovchenko, A. I. Usenko, 1954), the thickness of this formation in borehole 491 is no less than 150 or 155 m. Borehole 1649, according to the drill log data, penetrated a stratum of dolomite, siderite, and magnesite 184. 42 m thick (165. 02 to 349. 44 m interval). The buckling of the beds in this section and the bending of the borehole are negligible. As to the upper carbonaceous member Bak$_{10}$, the thickness of which, after Yu. A. Davydenko [5], does not exceed 100 m, it should be mentioned that this figure is correct as far as Bulandikha Mountain is concerned. This, in fact, is noted in my work, but on page 54, to which the authors refer, are given the thickness data for the Vostochnyy mine. The thickening of the Bak$_{10}$ stratum in the north is clearly discernible from the profile prepared by N. K. Burgelya ([12], Fig. 9). An increase in its thickness up to 120 or 130 m is also to be observed in the west, in the sections of boreholes 506, 562, 561, and up to 188 m in borehole 517.

Thus, from the above discussion it becomes clear that the statements of my opponents to the effect that I have ignored the basic features of the geologic structure of the Bakalian siderite deposits, that I have appropriated other people's materials, distorted facts, and so on, are groundless.

If these pronouncements of the said authors are attributable to the fact that they maintain a totally different point of view as to the genesis of the Bakalian siderites and strive to defend the hydrothermal and metasomatic hypothesis of their origin, then the method they have selected to conduct a scientific discussion is inconclusive, to say the least.

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LOSSES TO SCIENCE

NATAL'YA VASIL'YEVNA FROLOVA
(1907-1960)

The life of Natal'ya Vasil'yevna Frolova, a charming person and talented investigator, a geologist and petrographer, came to an abrupt end on July 18, 1960, after a long and serious illness in Moscow.

N. V. Frolova was born on October 25, 1907, in Baku. In 1930 she graduated from the Department of Geologic Prospecting of the Moscow Mining Academy.

While still a student, Natal'ya Vassil'yevna began her industrious professional career at the Institute of Applied Mineralogy. Soon she transferred to the Mining and Prospecting Bureau of the Krasnoural'sk Copper-Smelting Combine, and later to the All-Union Institute of Mineral Resources. From 1935 to 1941 whe was in charge of the Laboratory of Mineralogical Analysis at the Institute of Geologic Sciences of the U. S. S. R. Academy of Sciences. In August 1941 she was sent to western Siberia, where she worked in the Petroleum Prospecting System, and then at the "Sibeolnerud" Trust of the Irkutsk Geological Board as senior petrographer, and later as a consultant.

Much of her efforts and time Natal'ya Vasil'yevna devoted to teaching. Between 1932 and 1935 she successfully conducted a course in petrography and mineral resources at the Moscow Geologic and Geodetic Technical School. It was then that she had published a textbook on petrography which was received as one of the best. Since 1946, after having defended her dissertation for Candidate, for a period of many years she conducted a course in petrography at the Irkutsk State University. Her lectures and reports, profound in substance and brilliant in form of presentation, invariably attracted large audiences.

The range of Natal'ya Vasil'yevna's interests was broad and varied: her attention was devoted to the problems of regional geology of the Russian platform, the Caucasus, the Urals, western Siberia, and Yakutiya; to the general problems of metamorphism, the genesis of granite, the geology of mineral deposits, lithology, and so on. She is the author of more than 50 studies, a half of which were published.

Her research papers on the geology of the deposits of the Urals, Mangyshlak and the Caucasus, western Siberia, and Yakutiya are theoretically interesting, and practically important. Particularly noteworthy is her attempt at defining a regular relationship between the age of the U. S. S. R. zones of folding and their ore deposits.

She dedicated many years to lithologic investigations, having thereby shown herself to be a subtle analyst, for whom the study of the chemical composition of sedimentary rocks served as a basis for geologic and genetic conclusions.

Natal'ya Vasil'yevna was in perfect command of the stratigraphic method. The schemes that she developed on the stratigraphy of the thick Lower Precambrian carbonaceous series in the southeastern part of the Siberian platform and of the Jurassic coal-bearing formations in southern Yakutiya may serve as brilliant examples of the achievements of Soviet stratigraphy. Of particular significance are her studies on methods of detailed stratigraphic subdivision of the highly metamorphosed Archean series in western Siberian and Yakutiya. These studies have attracted wide attention, reflected in methodologic manuals, and have furnished an effective basis for exploration for a number of minerals, phlogopite in the first place. Here, at the meeting point of two branches of geology, stratigraphy and metamorphic geology, Natal'ya Vasil'yevna was a pioneer travelling along the hard, unbeaten, yet honorable path of a genuine investigator.

Of greatest theoretical interest are her works on the Archean strata of the Aldan shield. In analyzing the mineralogic and petrographic composition of these formations, Natal'ya Vasil'yevna was able to show conclusively that they represent strongly metamorphosed sedimentary rocks formed by the disintegration products of the "basaltic layer" of the earth's crust. On the basis of these data she developed ideas on the intensive erosion in Archean time which contributed to the formation of the primary sedimentary mentle on our planet. In her

opinion, the initial process of granitization occurred after the deposition of the Archean para-rocks as a result of a grandiose regional metamorphism and ultrametamorphism, which was followed by a general change in the thermal conditions in the earth's crust, as was indicated some time ago by V. I. Vernadskiy. Her ideas, expressed in her work "On the conditions of sedimentation in the Archean era" (1951) and in a number of other articles, were met with a lively and positive response in broad circles of Soviet and foreign geologists.

A talented scientist, a person of exceptional warmth and strong will, has prematurely passed away. Her unforgettable image will remain with us.

N. S. Shatskiy, D. S. Korzhinskiy, A. L. Yanshin, A. V. Peyve, N. A. Shtreya, V. S. Yablokov, V. V. Tikhomirov.

LOSSES TO SCIENCE

W.J. ARKELL
(1904-1958)

William Joselyn Arkell, an outstanding British stratigrapher and paleontologist, was born on June 9, 1904, in Highvor, Wiltshire County, near Oxford. As a school-boy he was interested in entomology, particularly in the diptera. At Oxford University, where he registered in 1922, he worked under the guidance of W. J. Sollas and J. Huxley and was enthralled by geology and biology. Upon graduation he began to study the geology of Jurassic formations and engaged in the description of the ammonites and other fossils which he had been eagerly collecting since his childhood days.

Although V. D. Arkell was a member of the Oxford University Council, he never taught there. His entire life was dedicated to science alone. In 32 years he published fourteen fundamental monographs and more than 180 papers.

V. D. Arkell's initial studies were devoted mainly to the Jurassic deposits in the environs of Oxford, which are famous for their coral limestones abounding in remnants of pelecypods, ammonites, and corals.

In 1927 he put out a monograph on the pelecypods of coralline facies (A Monograph of British Corallian Lamellibranchia).

His fundamental monograph The Jurassic System in Great Britain, which is distinguished for the completeness of its description of the classical massive Jurassic deposits was published in 1933. These deposits were used by W. Smith when he originally applied the paleontologic method to the development of stratigraphic problems.

V. D. Arkell was a worthy successor to W. Smith. In his book he has minutely analyzed the significance of stage, zonal differentiation of the Jurassic formations by D'Orbigny, K. Oppell, and W. Bookman, and has shed light on the paleogeographic peculiarities of the Jurassic system in England, as well as on the distribution of the facies in the various basins of that time.

With this book of world reknown, V. D. Arkell initiated a wide cycle of investigations in the fields of stratigraphy and faunal assemblages of the Jurassic in England. Among these, the monographs published in the Transactions of the Paleontographic Society on the ammonites of the Corallian beds (A Monograph on the Ammonites of the English Corallian Beds, 1935-1958) are widely popular, as well as numerous papers on stratigraphy, ammonites, and the remanants of other groups of organisms from the Jurassic formations of England.

In studying these formations, and in familiarizing himself with the building stone deposits corresponding to them, V. D. Arkell liked to visit the old quarries in the vicinity of Oxford and other places and to chat with the quarrymen. The results of these observations and talks were incorporated in his books The Geology of Oxford (1947) and Oxford Stone (1947). In 1953, together with S. I. Tomkeyev, he published a handbook, English Rock Terms, Chiefly as Used by Miners and Quarrymen.

Gradually, the range of V. D. Arkell's interests became wider. He visited Arabia, Algeria, France, Germany, and the U. S. A., and began to work on a generalization of data on the geology of the Jurassic formations of the world.

His Standard of the European Jurassic appeared in 1946.

In 1947 he was elected member of the London Royal Society, and also Fellow of a Cambridge College, and began to work in the Geologic Laboratory of the Sedgewick Museum.

His classification of the Jurassic ammonites, which is now adopted in the majority of the world's reference publications, appeared in the Paleontological Journal in 1950. In 1954, in co-authorship with P. E. Playford, he published a description of the Bajocian ammonites of western Australia (The Bajocian Ammonites of Western Australia).

His articles analyzing the general problems of stratigraphic taxonomy and nomenclature were published in various journals throughout the years 1950-1957.

The last fundamental monograph by V. D. Arkell, Jurassic Geology of the World, came as a result of these investigations. It summarized all the information dealing with the Jurassic deposits in the world and their fauna. A large place is devoted in this survey to the history of boreal deposits and an analysis of the Jurassic formations in the Soviet Union.

Not only Jurassic deposits and their fossils were the object of V. D. Arkell's studies. Almost immediately upon graduation from Oxford University, he together with K. S. Sanford, became engaged in a long study (1926-1930) of the paleolithic cultures and Quaternary formations of Egypt. In the years 1933-1939 he published three capital surveys of Paleolithic man and the Nile Valley in Nubia and Egypt (Paleolithic Man and the Nile Valley in Nubia and Upper Egypt. 1933; Upper and Middle Egypt 1934; Lower Egypt with Some notes upon a Part of the Red Sea Littoral 1939).

In his subsequent works, V. D. Arkell repeatedly reverted to the problems of Quaternary geology. He analyzed the structure of the Quaternary deposits in northern Cornwall (1934), of the Oxfordian paleolithic (1940), and also revised the question concerning the correlation of the Thames terraces and the Alpine glaciations (1951).

In spite of his healthy appearance and his athletic constitution, V. D. Arkell, all his life, suffered from pulmonary TB.

Succombing to the hard strains of his work in recent years, he passed away on April 18, 1958, in Cambridge.

In the person of V. D. Arkell the geologic science has lost one of the greatest stratigraphers and paleontologists, who enjoyed great popularity both in foreign countries and in the Soviet Union. His studies facilitated the correlation of the Jurassic strata in the U.S.S.R. and in England, a subject to which A. P. Pavlov has devoted great attention, and were of great importance for the clarification of the stratigraphy of the Arctic regions. Particularly significant is the role of V. D. Arkell in the development of a single stratigraphic scale for the Jurassic deposits in the world. His works will long serve as a basis for many subsequent investigations.

S. I. Tomkeyev, V. V. Menner, N. P. Mikhaylov.

CHRONICLE

IN THE DIVISION OF GEOLOGICAL AND GEOGRAPHICAL SCIENCES OF THE U. S. S. R. ACADEMY OF SCIENCES[1]

A general meeting of the OGGN (Division of Geological v Geographical Sciences) of the U. S. S. R. Academy of Sciences was held on June 8, 1960, in Moscow. On this occasion two reports were presented: Glaciologic Investigations of the International Geophysical Year by Professor G. A. Avsyuk, and Paleomagnetism and its Significance for Stratigraphy and Geotectonics by P. N. Kropotkin, doctor of geologic and mineralogic sciences.

G. A. Avsyuk said that the IGY glaciologic investigations were carried out in all principal areas of present-day glaciation, from both poles to the equator. This includes the investigations conducted in the Antarctic, a previously totally unexplored region of glaciation, which is of exceptionally great importance for the study of the earth.

The greatest volume of work was accomplished by the Soviet Union and the USA. Both nations had 17 stations each (6 in the Antarctic and 11 on their own proper territories).

The basic objective of glaciologic surveys was the study of the accumulation, transformation, movement, and melting of ice on the surface of the earth depending on the heat balance of the latter, and also the role played by ice in water circulation on our planet.

The foremost problem in the processing of the data obtained during the IGY consists in the following. To determine: the interaction of glaciation and climate; the contemporary state, spatial distribution and thickness of glaciation; the direction of its evolution at the present time; the zonal and regional peculiarities of its development. Directly associated therewith is the study of ancient glaciations, particularly, of their dynamics and effect on the evolution of the earth.

A great deal of new factual material, collected through simultaneous systematic observations, was obtained as a result of the IGY. This makes it possible to continue further investigations of the natural regularities in the glaciation of the earth, and on their basis to produce interesting scientific generalizations. Without exageration, one may say that the glaciologic surveys of the IGY period have opened a new epoch in the development of glaciology.

Although the processing of the information on glaciology obtained during the IGY is not yet completed, it is already possible to speak of two important conclusions resulting from these observations, namely: 1) The ideas on the volume of the ice masses constituting present-day glaciation were incorrect. According to the new data it is far greater than previously estimated, and is equivalent to the volume of 30 million sq. kilometers. This amounts to about 2% of the oceanic water volume, and exceeds by approximately 7 times the volume of continental waters. This ice-mass volume is capable of raising the level of the world ocean by a value of about 70 m. 2) Present-day glaciation all over the world is in a stage of retreat but the rate of this retreat varies in different regions. It is true that conditions favorable for the development of glaciation were registered in a number of areas, but it is still premature to draw any conclusions on a possible change in the direction of its evolution.

P. N. Kropotkin's report will be published in full in one of the next issues of the "Bulletin of the U. S. S. R. Academy of Sciences, Geological Series".

Elections were also held at this meeting of the D. G. G. S. of the Academy of Sciences. The candidature of Yevgeniy Konstantinovic Fedorov, Associate Member of the U. S. S. R. Academy of Sciences, was approved for recommendation to the General Assembly of the U. S. S. R. Academy of Sciences for the open vacancy of Academician in the field of applied geophysics. Lhe open vacancy for an Associate Member of the U. S. S. R. Academy of Sciences in the field of hydrogeology was filled through the election of Prof. Grigoriy Aleksandrovich Avsyuk.

In discussing the candidatures, the speakers participating in the debate, Academician I. P. Gerasimov, Academician A. G. Betekhtin, Academician D. V. Nalivkin, N. I. Sokolov, doctor of geologic and mineralogic sciences, N. A. Taytovich, Associate Member of the U. S. S. R. Academy of Sciences, all pointed out the insufficient number of members in the division of Geological and Geographical Sciences of the U. S. S. R. Academy of Sciences, as a result of which many branches of geology and geography are not represented by responsible specialists in the Academy of Sciences. In the opinion of the D. G. G. S. members who took the floor, the leadership of the Division should prepare the necessary materials and argumentation for the next elections in order to procure a number of vacancies for Academicians and Associate Members sufficient to assure the further development of the geologic and geographic sciences.

The general meeting of the D. G. G. S. elected directors for the following institutions: Ivan Vasil'yevich Popov, doctor of geologic and mineralogic sciences, for the Laboratory of Hydrogeological Problems; Albert Ivanovich Olli, doctor of geologic and mineralogic sciences, for the Mining and Geological Institute of the Bashkirian Affiliate of the U. S. S. R. Academy of Sciences; Yevgeniy Konstantinovich Kozlov, doctor of geologic and mineralogic sciences, for the Geological Institute of the Kola Peninsula Affiliate of the U. S. S. R. Academy of Sciences; Aleksandr Alekseyevich Pronin, Doctor of geologic and mineralogic sciences, for the Mining and Geologiccal Institute of the Uralian Affiliate of the U. S. S. R. Academy of Sciences.

CONFERENCE ON THE REGIONAL MECHANISMS OF FORMATION AND DISTRIBUTION OF COPPER-ORE DEPOSITS[2]

by

T. Ya. Goncharova

From April 19 to April 23, 1960 a conference took place in Moscow on the mechanisms of formation and distribution of copper-ore deposits, mostly of the chalcopyrite and copper-porphyry types. The conference was convened by the Interdepartmental Commission for the study of the Regularities Doverning Endogenic Ore Deposits.

The Conference heard and discussed 45 reports and communications devoted to the problems of regional distribution of chalcopyrite and copper-porphyry deposits in the geologic structures of major cupriferous provinces of the Soviet Union: the Urals, Caucasus, Altay, Kazakhstan, and western Siberia.

The discussion of the points on the agenda was opened with the report by A. A. Amiraslanov on the Geologic features of various types of copper deposits, their relative industrial valuation, and the problems facing the geologic organizations concerned with the expansion of the nation's mineral resources. The report provides a brief geologic, structural, and mineralogic description of the specified types of copper-ore deposits, and also emphasizes their specific peculiarities.

After D. S. Korshinskiy's report on the problem of the depth of formation of pyritic and copper-porphyry deposits, reports and statements dealing with individual regions were presented to the meeting.

On the basis of a generalization of geologic data on the Urals, S. N. Ivanov has outlined the principal problems connected with the study of the regularities governing the distribution of the pyritic-type deposits.

V. P. Loginov and I. V. Lennykh dwelt in their communications on the close spatial and paragenetic relationship of pyritic mineralization in the Urals to the spilitic-keratophyre Silurian and Devonian complex. They emphasized the contemporaneity of the mineralization and these formations, in proving this through the coincidence of these deposits with definite stratigraphic horizons. Furthermore, they substantiated this fact by discoveries of pebbles and fragments of pyritic ore and quartz-sericitic rocks in the conglomerates and volcanic breccia of the above-ore strata; by the intersection of the pyritic deposits and dikes of porphyrites synchronous with the ore-bearing and superincumbent extrusive rocks, and also by determining the absolute age of the sericite from the hydrothermally-altered rocks located near the ore.

V. I. Skripel', L. I. Yakovlev, and V. L. Rusinov also relate the formation of pyritic deposits to the concluding stages of volcanic activity. On a basis of combined lithologic, facies, and structural characteristics of the rocks in Gayskoye ore field, V. I. Skripel' came to the conclusion that the ore-enclosing structure is originally of volcanic. This structure represents a part of the volcanic apparatus complicated and deformed by subsequent folding. L. I. Yakovlev and V. L. Rusinov have focused their attention on the availability of a time gap between the pyritic and pyritic-polymetallic mineralizations which are respectively associated with the initial and more recent stages of geosynclinal development.

In the reports of M. B. Borodayevskaya, A. D. Rakcheyev, P. I. Kutyukhin and A. P. Nasedkin, P. I. Yegorov, A. A. Korol'kov, Ye. A. Murav'yeva, A. V. Purkin and D. K. Suslov, Yu. M. Stoyarov, and V. P. Pervov, the decisive role in the distribution of pyritic mineralization is ascribed to structural control.

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[2]Soveshchaniye o regional'nykh zakonomernostyakh formirovaniya i razmeshcheniya mednykh mestorozhdeniy.

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M. B. Borodayevskaya elucidated in her communication certain problems connected with the history of the structural development of ore fields in the southern Urals, and particularly, with the localization of orebodies in them. In terms of the correspondence of mineralization to the structural stages she identifies three types of structures for pyritic deposits.

The communications of N. V. Petrovskaya, A. V. Prokin, A. I. Schmidt, and P. I. Teteryuk were devoted to the problems of the mineral composition of pyritic ores, hydrothermally altered rocks, the change of pyritic mineralization into streaked, impregnated, and skarn-type deposits.

G. A. Tvalcherlidze, S. A. Vakhromeyev, Ye. A. Kuznetsov, N. A. Silin, A. N. Fenogenov, and G. F. Chervyakoskiy took part in the ensuing discussion of the reports. S. A. Vakhromeyev explains the geologic peculiarities of the central and southern Ural ore deposits by the different depths of their formation. G. F. Chervyakovskiy observed that pyritic mineralization in the Urals originated at different times and is not genetically uniform. There are syngenetic deposits associated with fumarolic-solfataric activity, and there are epigenetic deposits constituting products of later magmatic activity.

In reports dealing with northern Caucasus, a unanimity of views was expressed with regard to the existence of a close paragenetic relationship between pyritic mineralization and volcanic activity.

Confined to problems of regional distribution of chalcopyritic ores in northern Caucasus was the report made by V. I. Smirnov and T. Ya. Concharova. They believe that all pyritic mineralization is not synchronous, that it coincides with three metallogenetic epochs and corresponds, respectively, to three differently aged sedimentary-volcanic complexes: the lower Paleozoic, Lower and Middle Devonian, and Lower Carboniferous. They attribute a great role in the localization of pyritic mineralization in northern Caucasus to the evolution of volcanism.

The subjects of close relationship between pyritic mineralization in northern Caucasus and volcanism, the coincidence of mineralization with the zones of highes manifestations of acid extrusive rocks, its correlation with the dikes, and the indications of dynamo-metamorphism in the ores, were dealt with in the communications of A. V. Pek and N. S. Skripachenko, Ye. A. Snezko, V. F. Povetkina, V. I. Buadze, V. V. Sviridov, and I. Ya. Baranov.

From reports devoted to the pyritic mineralization in the minor Caucasus it became evident that there is, so far, no uniform opinion on the age and method of formation of pyritic deposits in this province.

S. S. Mkrtchyan, G. I. Kerimov, A. G. Kazaryan defended the view that pyritic mineralization is associated with plutonic magmatism.

S. Sh. Sarkisyan, and E. A. Khachaturyan maintain the position that pyritic mineralization is connected with subvolcanic intrusions of albitophyres and quartz porphyries and identify a group of volcanic and subvolcanic deposits.

P. F. Sopko, S. S. Vanyishin, and Yu. A. Leye consider the pyritic mineralization of the minor Caucasus as not synchronous and connected with the early stages of three tectonic-magmatic complexes: Jurassic, Cretaceous, and Eocene. In the emplacement of pyritic deposits among sedimentary-volcanic formations, the decisive role is attributed to structural, lithologic, and magmatic factors.

Discussed at the meeting also were the distribution regularities of pyritic and pyritic-polymetallic deposits of Altay, Kazakhstan, Salair, and western Siberia.

P. F. Ivankin's report covering the copper and polymetallic deposits in Rudnyy Altay was based on the theory of a complex and continuous development of magmatic (volcanic and intrusive) activity, its abatement towards the end of the late Paleozoic and a counter-process of increasing ore-formation.

Ye. T. Makovkin, K. M. Mukanov and N. K. Nechayev gave a description of the geologic structure of a group of chalcopyrite deposits deposits in Kazakhstan (Abastau geanticline of the Chinghiz Range).

The mechanism of formation and emplacement of copper-pyrite deposits in the north-eastern part of the Salair Ridge was discussed by V. M. Dvoryanov and V. I. Zerkalov.

Attention was also given to the communications presented by Yu. V. Pogodin and A. S. Yarmolenko about copper mineralization in the southern part of the Siberian platform and in the Krasnoyarsk region. The different types of copper mineralization developed there are related by the authors to minor intrusions, sills, and trap dikes. The predominant significance in their spatial localization is attributed to the structural factor.

A number of reports dealing with the problem of the formation and distribution of copper-molybdenum banded and impregnated ore deposits in Armenia and Uzbekistan were presented.

A survey was made by I. G. Magakyan, S. S. Mkrtchyan, and G. O. Pidzhyan in their report of the regularities of regional distribution of copper-molybdenum deposits in Armenia against the background of the specific features characterizing the formation of this type of deposits in other provinces of the world.

R. A. Musin, T. Z. Zakirov, and I. B. Fedorova presented a report on the magmatic, geologic and structural control in the localization of copper mineralization in the Almalyk region of Uzbekistan.

The report of Yu. V. Bogdanov was devoted to cupriferous sandstones. He gave a description of the geologic structure, conditions of formation and the distribution of the cupriferous sandstones in the region of the Udokanskiy Range (the southwestern fringe of the Aldan massif). Yu. V. Bogdanov believes that the conclusion concerning the control of sedimentary mineralization by lithologic and facies peculiarities in the accumulation of copper-bearing rocks is fully proven as far as the Udokanskiy region is concerned.

Attention was drawn in A. I. Germanov's, S. I. Ivanov's and G. A. Kuritsina's communication to the bitumen content in pyritic ores and the effect of the organic matter on the formation of sulfides.

L. S. Tarasov dwelt on the analysis of the isotopic composition of lead in the ores of certain copper and copper-polymetallic deposits in Altay and Kazakhstan.

N. I. Vorontsov, V. S. Domarev, V. N. Kotlyar, V. G. Grushevoy, S. N. Ivanov, V. S. Koptev-Dvornikov, and A. V. Pek took part in the discussion of the reports.

In his closing speech, V. I. Smirnov emphasized the fact that at the present time there exists no single viewpoint on the method of formation and distribution of pyritic deposits for many provinces with pyrite-bearing formations in the country. However, inspite of the existence of some unsolved and debatable questions, a number of important positions unquestionably accepted by the majority of geologists have been outlined. Characteristic of chalcopyrite deposits is their coincidence with sedimentary and volcanic deposits of the early stages of development of geosynclines which usually fill the narrow troughs. The section of the ore-enclosing rocks shows a relationships of pyritic mineralization to definite stratigraphic complexes, whereas strike-wise pyrite deposits are grouped into ore clusters. The reasons for such mechanisms in the localization of copper-pyrite deposits are explained in various ways by different geologists, but objectively these regularities exist and their further study will lead to a more accurate definition of their nature.

A resolution was adopted at the end of the conference. This resolution indicates that expansion of the ore reserves for the copper industry in our country constitutes one of the most important geologic problems of the present day. A considerable increase of copper re-sources may be achieved through the development of the deposits of pyritic, copper-porphyry, and cupriferous sandstone ores.

The conference has outlined the directions for further investigations in the geology of copper ore deposits, which are important for the development of the scientific basis for prospecting and exploration.

SCIENTIFIC SESSION ON THE STUDY OF THE LAWS GOVERNING THE DISTRIBUTION OF PLACERS[3]

by

Ye. M. Kamshilina

This session was held in Moscow from November 30 through December 3, 1959, under the auspices of the Commission on the Study of the Laws Governing the Distribution of Placers of Ore Minerals of the Division of Geological and Geographical Sciences of the U. S. S. R. Academy of Sciences.

Participating in the transactions at this session were the representatives of the geologic institutes of the U. S. S. R. Academy of Sciences, territorial geologic organizations, scientific-research institutes of the Ministry of Geology and the Protection of Mineral Resources of the U. S. S. R., Regional Economic Administrations, as well as representatives from various scientific-research institutions of the Academies of Sciences of the Union Republics, the Ministry of Higher and Secondary Specialized Education of the U. S. S. R. Altogether, 24 papers were presented.

Most of the reports dealt with the mechanisms of distribution of gold and titanium placer deposits in various parts of the U. S. S. R., and placers of diamonds in the Siberian platform. In some papers, analyses were made of the new systems of genetic classification of placers.

In his report, I. S. Rozhkov, Associate Member of the U. S. S. R. Academy of Sciences (Yakutian Branch of the Siberian Affiliate of the U. S. S. R. Academy of Sciences) gave a description of the main factors controlling the formation of placers: type of original sources, climatic conditions, character of the tectonic movements and the erosive accumulating activity. A classification was made in the report of the placer-deposit provinces in the U. S. S. R. to which definite age-groups of placers are related. Particular attention was given to investigations of ancient buried placers.

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[3]Nauchnaya sessiya po probleme izucheniya zakonomernostey razmeshcheniya rossypey.

N. A. Shilo (Magadan Scientific-Research Institute) indicated in his paper that spatial localization of placers is determined by the tectonic and geomorphic development of the earth's crust and by the nature of continental lithogenesis. Under conditions of subpolar climate, the process of placer formation develops most actively during the alluvial stage of placer accumulation.

According to the data contained in S. S. Konovalenko's (Bashkirian Economic Administration) report, the original auriferous deposits of the quartz-lode and shear-zone type, genetically connected with middle and upper Paleozoic intrusions and Middle Cenozoic extrusives (rocks of the "greenstone" zone in the southern Urals), served as the source of the gold placers located on the eastern slope of the southern Urals.

Both ore and placer deposits of gold occur in the Altay-Sayan fold zone. The presence of gold here is closely associated with granodiorite intrusions of pre-Silurian and, possibly, Hercynian age, as well as with an ultrahypabyssal intrusion of Cambrian quartz keratophyres, and corresponds to practically all the beds of unconsolidated formations from the Aptian and Albian through to the Holocene. Of principal commercial value are the placers of Upper Pleistocene age in recent valleys. Bench placers of different age are well developed, as well as buried placers located at the watersheds and in recent valleys.

The principal auriferous alluvial placers of the Yeniseysk Ridge are distinguishable for their length and simple structure.

According to Yu. P. Kazakevich's (TsNIGRI) data, the most considerable gold-bearing placers in the Vitimo-Patomskoye upland correspond to the Bodaybinskiy synclinorium, inside of which of foremost importance are the major synclines and synclinal bowls. The central part of the upland constitutes a Cenozoic depression with wide development of buried Lower and Middle Pleistocene placers. This depression embraces almost entirely the Bodaybinskiy Proterozoic synclinorium. Minor placers of creek and river-bar types dating back to the late Pleistocene and Holocene are developed in the section of the upland which abuts on the depression from the west, north, and east. The recent alluvium in the peripheral parts of the upland contain commercial concentrations of gold.

In the paper presented by S. G. Mirchink (TsNIGRI), it is noted that the structural peculiarities of gold-bearing placers are determined by the general character and general orientation of the young tectonic movements, and that spatial distribution of auriferous placers is closely related to the distribution of the deeply eroded ore deposits located in the zones of pre-

vailing tectonic uplifts. The mode of occurrence of auriferous placers and the mechanism of their distribution in the valleys of the ancient and recent river systems are determined by the uneven tectonic movements.

The report of M. F. Veklich, M. G. Dyadchenko, V. Yu. Kondrachuk, and A. Ya. Khatuntseva, as well as that of N. M. Baranova, M. F. Veklich, M. G. Dyadchenko, P. K. Zamoriya, and G. I. Molyavko (Institute of Geological Sciences of the Ukrainian S. S. R. Academy of Sciences) were devoted to placers of Pre-Tertiary and Cenozoic ages. The most promising Pre-Tertiary deposits are the Mesozoic, and partly Paleozoic, formations of the Ukrainian crystalline shield. Stages particularly favorable for the formation of placers may be identified in the Cenozoic: the early Paleogene, Poltavian, late Miocene, early Quaternary, Dneprovian, late Pleistocene, and Holocene. Various types of commercial placers were formed during these stages. Six regions of placer development may be identified in the territory of the Ukrainian S. S. R.

S. I. Gurvich, A. P. Romodanov, and A. Ya. Khatuntsev (Geologic Prospecting Trust No. 1, Institute of Geological Sciences of the Ukrainian Academy of Sciences) have elucidated the problem of the distribution of rare-earth metals and titanium placers in the northern extremity of the Ukrainian crystalline shield. It was indicated that these placers coincide with the ancient negative forms of relief filled with Paleogene and Quaternary deposits.

I. Ye. Drabkin, I. N. Skorin, M. I. Suvorov, A. V. Khripkov, and M. D. El'yanov (Northwestern Geological Administration) discussed the main principles of prospective evaluation based on a study of the laws governing the distribution of placer deposits, as exemplified in the northwest.

Special factors which influence the prospective estimates of gold-bearing areas were analyzed. The regularities in the qualitative and quantitative distribution of gold in the placers were specified. The geologic statistical method based on the ratio of alluvial gold output per water-system unit was successfully employed for prospective evaluation of the northwestern placers. The principles of prospective evaluation in the northwest may be recommended for application in other regions.

In their report on the distribution regularities of rutile placers in the U. S. S. R., P. A. Trokhachev and L. P. Kostyunina (Geologic Prospecting Trust No. 1) have indicated the areas where discoveries of major beach complex placers of Rutile were made in recent years. These placers are of Mesozoic and Cenozoic age, as well as ancient Pre-Mesozoic placer deposits.

V. M. Chayka (Uralian Geologic Adminis-
tration) has devoted his paper to the Precam-
brian titanium and zirconium placers of the
Bashkirian upland and Ural-Tau. The Bashk-
irian upland represents an ancient folded struc-
ture made up of a thick complex of a metasedi-
mentary, poorly metamorphosed, Riphean
series. Coinciding with the upper part of this
series (Zilmerdakskaya suite) are the zircon-
rutile-hematite placers. Two promenance
areas were identified: the principal one lo-
cated in the west (Russian platform) and the
local one (the axial zone of the Urals). A
regular distribution of sedimentary deposits of
iron, titanium, and magnetitic ores among the
Riphean formations of the Bashkirian geanti-
cline was recorded.

S. I. Gurvich, V. I. Pyatnov, I. B. Sandalov,
A. S. Stolyarov, P. A. Trokhachev, and V. A.
Yankovskiy (Geological Institute of Rare-Earth
Metals) emphasized the great potentialities of
the marginal zones of the west Siberian low-
land with respect to zircon-ilmenite placers
attributable to three productive intervals:
a) Aptian-Albian-Kyian strata; b) Senonian-
Danian-Antibessian and c) Middle Oligocene
(Tuganian formation). In recent years, zircon-
ilmenite placers of commercial importance
were discovered in formations of this age.

Information on the placers of the Kola
peninsula was furnished in the paper presented
by A. V. Sidorenko, Associate Member of the
U. S. S. R. Academy of Sciences (Kola Branch
of the U. S. S. R. Academy of Sciences). The
formation of placers on the Baltic shield was
facilitated by such factors as the high content
of valuable heavy minerals in Precambrian
rocks, continental conditions, of long duration
and the complex geologic history of the shield
at the end of the Cenozoic (processes of pre-
glacial erosion, Quaternary glaciation, and
marine transgression).

The following complexes of rocks may be
specified here as possible sources of placer
formation: 1) Precambrian metamorphosed
strata of conglomerates and gravel beds; 2)
ancient preglacial continental deposits (pri-
marily eluvial and alluvial); 3) Quaternary
glacial sediments (fluvioglacial deposits and
formations of washed ground moraine); 4)
marine and lacustrine littoral, interglacial,
postglacial, and recent, deposits; 5) Quaternary
and recent alluvial deposits.

A description of the ancient diamond placers
of the Siberian platform was given in the paper
by G. Kh. Faynshteyn and M. M. Odintsova
(Yakutian Geologic Administration). They were
formed by processes of disintegration and deep
chemical alteration of kimberlite as a result of
several stages of weathering. The age of the
kimberlite pipes in southwest Yakutia is post-
Lower Triassic and pre-Rhaetian-Lias, whereas

the kimberlite pipes in the northern part are of
different ages. Only the Rhaetian-Lias alluvial,
and the Cenozoic alluvial, and eluvial, placers
are of commercial importance, so far.

Results of research carried out in a model of
a river bed were reported in the paper presented
by N. V. Razumikhin and Z. N. Timashkova (Cen-
tral Experimental Laboratory of VSEGEI). The
concentration of light and heavy minerals as ob-
served in the conditions leading to the formation
of diamond river placers was studied. The in-
creased content of the heavy fraction and dia-
monds occurs in the head sections of the upper
banks of sand bars adjacent to the fairway zone
of the stream, and also in the center of the reach
depression.

The accumulation of diamonds in the river
bed also depends on the rocks of which it is
made up. It has been determined that certain
types of clay are more propitious for accumu-
lation of diamond crystals than other river drifts.

Three papers were devoted to the genetic
classification of placers.

In V. S. Trofimov's (GIN AN S. S. S. R.) re-
port, the formation of different genetic types of
placers is considered as a single process con-
sisting of several stages. He specifies the fol-
lowing types of placers: alluvial, flood deposit,
and gravitational, proluvial, beach, marine
and lacustrine, glacial, and eolian. Each type
may be subdivided into morphologic subtypes.
The formative sequence of the individual genetic
types of placers is also characteristic of ancient
sedimentary formations.

N. P. Kheraskov, K. V. Potemkina, and A. N.
Spitsyna (IMGRE AN S. S. S. R.) in their paper
entitled Types and Peculiarities of Formation
and Distribution of placers of Minerals Con-
taining Rare and Scattered Elements propose
to classify the placer deposits into three geologic
types:

1) with negligible migration of ore minerals
from the original source - eluvial, flood deposit,
and partially alluvial genetic types;

2) of river valleys (placers of river valleys
proper, and placers of alluvial plains);

3) of water bodies; these include the largest
and richest commercial concentrations of rare-
earth minerals.

A system of genetic classification of placers
in the west Siberian lowland is proposed in the
report The Genetic Types of Placers in the
west Siberian Lowland and Certain Regularities
of Their Distribution by V. A. Dergevich, V. F.
Ignatova, and V. K. Kashtanov (Siberian Scien-
tific-Research Institute of Geology and Geo-
physics and Mineral Raw Materials). The

authors introduce the concept of "genetic
series", i.e., a continuous series of placers
related by gradual transitions, and formed in
the process of gradual alteration of the sedi-
ments as they moved from one facies zone into
another, as well as a result of a change of
facies circumstances in the area of deposition
of sediments enriched by placer minerals.
Specified are two genetic series divided into
stages corresponding to the following genetic
types. The first genetic series: eluvial-flood
deposit, and alluvial placers, as well as placers
of lacustrine-alluvial plains. The second genetic
series: beach placers, and also placers of
seaboard and lacustrine-alluvial plains in com-
bination.

Interesting and lively discussions developed
at the Session. Many statements were devoted
to the problem of the influence produced by
tectonic movements on the distribution of
placers, on the significance of geomorphologic
investigations for placer prospecting, on further
development and generalizations of materials
relative to the laws governing the formation
and distribution of placer deposits.

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